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(12-47)

DOUGLAS AIRCRAFT COMPANY, INC.

EL SEGUNDO PLANT

Engineering DEPARTMENT

DOUGLAS

REPORT NUMBER

ES 15304

STABILITY AND CONTROL CHARACTERISTICS OF DOUGLAS

MODEL XF4D-1

PART I. LOW SPEED FLYING QUALITIES

CONTRACT NO.

REPORT DATE [illegible]

MODEL XF4D-1

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PREPARED BY Aerodynamics *

SECTION OR GROUP Stability & Control

E. R. Heald

APPROVED BY K. E. Van Every
Chief, Aerodynamics Section

APPROVED BY [illegible]
for Chief Engineer

* W.W. Huff, Jr.

REVISIONS

LETTER	DATE	PAGES AFFECTED	REMARKS

1.0 ABSTRACT

Estimated low speed stability and control characteristics of Douglas Model XF4D-1 airplane are presented in this report. Based on analysis of wind tunnel tests conducted on the latest configuration, the flying qualities are summarized below. The conclusions presented below may be considered applicable up to a Mach number of 0.8 since Mach number effects are known to be minor up to that speed.

FLYING QUALITY	REMARKS
1. Static Stick Fixed Longitudinal Stability.	Satisfactory over low speed range for an aft CG of 25% MAC. Minimum of 5% static margin maintained for all speeds at which Mach number effects are negligible.
2. Static Stick Free Longitudinal Stability.	Satisfactory during normal control conditions and emergency control conditions.
3. Trim Change Characteristics	Excellent.
4. Dynamic Longitudinal Stability	Damping of short period oscillation does not meet requirements of SR 119-B. Control system should be designed so that artificial damping can be added if necessary.
5. Elevator Control Power	Satisfactory. Hold-off 1.05 V_{stall} satisfactory for C.G. at 22% MAC, gear down. Nose-wheel lift-off can be effected at 90% of the minimum take-off speed with C.G. at 22% MAC.
6. Elevator Control Forces	Normal Control Configuration: Satisfactory. Emergency Control Configuration: Satisfactory during unaccelerated flight conditions. Stick force per "g" variation unavoidably high during turns and pull-ups above 200 knots.
7. Static Directional Stability	Satisfactory. Adverse yaw within requirements. Minimum C_{n_β} = .00110.
8. Rudder Control Power	Satisfactory.

9.	Rudder Forces	Satisfactory for airplane with no yaw-damper. Unknown as yet with yaw-damper installed.
10.	Dihedral Effect	Satisfactory but marginally high, stick fixed and stick free. No rolling velocity reversal.
11.	Dynamic Lateral Stability	Marginal with no artificial damping. Characteristics with rate-gyro installed estimated to be satisfactory.
12.	Lateral Control	Excellent.
13.	Aileron Forces	Satisfactory for both normal and emergency conditions over low speed flight range.
14.	Stalling Charecteristics	Satisfactory with nose-slats.

2.0 TABLE OF CONTENTS

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2.1 List of Figures

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2.2 List of Tables

3.0 COEFFICIENTS AND SYMBOLS

C_L	Lift coefficient, $\frac{L}{qS}$
C_D	Drag coefficient, $\frac{D}{qS}$
C_m	Pitching moment coefficient about quarter chord point of wing mean aerodynamic chord, $\frac{M}{qSt_w}$
C_ℓ	Rolling moment coefficient, stability axes, $\frac{R}{qSb}$
C_n	Yawing moment coefficient, $\frac{N}{qSb}$
C_c, C_Y	Side force coefficient, stability axes, $\frac{C}{qS}$
C_{h_e}	Hinge moment coefficient, $\frac{HM}{q\,S_e\bar{C}_e}$
$C_{h_{\delta r}}$	Variation of rudder hinge moment coefficient with rudder deflection
C_{ℓ_p}	Rolling moment due to rolling velocity
C_{ℓ_R}	Rolling moment due to yawing velocity
C_{n_p}	Yawing moment due to rolling velocity
C_{n_R}	Yawing moment due to yawing velocity
C_{Y_p}	Side force due to rolling velocity
C_{Y_R}	Side force due to yawing velocity
C_{n_β}	Yawing moment due to sideslip angle
C_{ℓ_β}	Rolling moment due to sideslip angle
C_{Y_β}	Side force due to sideslip angle
C_{L_α}	Lift curve slope
C_{D_α}	Variation of drag coefficient with angle of attack
$\frac{dC_m}{dC_L}$	Variation of pitching moment coefficient with lift coefficient

$\frac{\partial C_L}{\partial \delta_e}$ Variation of lift coefficient with elevon deflection

$\frac{\partial C_m}{\partial \delta_e}$ Variation of pitching moment coefficient with elevon deflection

C_{m_q} Pitching moment due to pitching velocity

η Angle of attack of principal longitudinal axis of airplane, positive when principal axis is above flight path at the nose, degrees

k_{X_o} Radius of gyration in roll about principal longitudinal axis, feet

k_{Y_o} Radius of gyration in pitch about principal lateral axis, feet

k_{Z_o} Radius of gyration in yaw about principal normal axis, feet

I_{X_o} Moment-of-inertia coefficient about principal longitudinal axis $\frac{m{k_{X_o}}^2}{qbS}$

I_{Y_o} Moment of inertia coefficient about principal lateral axis, $\frac{m{k_{Y_o}}^2}{qSb}$

I_{Z_o} Moment-of-inertia coefficient about principal normal axis $\frac{m{k_{Z_o}}^2}{qbS}$

I_X Moment-of-inertia coefficient about flight-path axis $(I_{X_o}\cos^2\eta + I_{Z_o}\sin^2\eta)$

I_Z Moment-of-inertia coefficient about axis normal to flight path $(I_{Z_o}\cos^2\eta + I_{X_o}\sin^2\eta)$

I_{XZ} Product-of-inertia coefficient with respect to flight-path axis and axis normal to flight path $[-(I_{Z_o} - I_{X_o})\sin\eta\cos\eta]$

m Airplane mass $= \frac{W}{g}$

$P = \frac{pb}{2V}$

$R = \frac{rb}{2V}$

where

p = rolling velocity, rad/sec.
r = yawing velocity, rad/sec.
b = wing span, feet
V = velocity, feet per sec.

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M = Mach number

S_w = Wing area, square feet

S_e = Elevon area, square feet

S_r = Rudder area, square feet

S_N = Trimmer area, square feet

t_w = Wing mean aerodynamic chord, feet

b_w = Wing span, feet

$\bar{C}_e$ = Elevon root mean square chord, feet

q = Dynamic pressure, pounds per square foot ($1/2\ \rho V^2$)

ρ = Mass density of air, slugs per cubic foot

V = Airspeed, feet per second

V_i = Airspeed, knots, indicated

α = Angle of attack of fuselage reference line, degrees

ψ = Angle of yaw of fuselage reference line, degrees

β = Sideslip angle of fuselage reference, degrees

ϕ = Angle of roll, degrees

δ_e = Elevon deflection angle, degrees, negative when trailing edge up

δ_r = Rudder deflection angle, degrees, " " " " right

δ_N = Trimmer deflection angle, degrees, " " " " up

4.0 INTRODUCTION

This report summarizes low speed stability and control characteristics of the final pre-flight-test configuration of Douglas Model XF4D-1. It is submitted to show expected low speed flying qualities in comparison with requirements of Bureau of Aeronautics Specification SR119-B.

Since Reference 3 was submitted, numerous changes in the configuration of the airplane made it advisable to verify estimated stability and control characteristics with wind tunnel tests of the up-to-date configuration. These tests were accomplished in two phases: low speed tests completed at Guggenheim Aeronautical Laboratory, California Institute of Technology in July, 1949 and presented in Reference 1, and transonic "bump" tests completed at the Southern California Cooperative Wind Tunnel in July, 1949 and presented in Reference 2.

Changes in the design of the airplane that have been incorporated into the final configuration and which effect stability and control are:

1. Change in shape and size of the fuselage
2. Decrease in chord of the elevons from 40" to 26", parallel to wind stream
3. Change in span-wise division between inboard and outboard portions of the elevon
4. Increase in total lateral deflection of the elevons from $\pm 15^{\circ}$ to $\pm 20^{\circ}$
5. Addition of auxiliary pitch trimmers located inboard of elevons to compensate the decrease in elevon chord

Items 2, 3, 4, and 5 were decided upon in an effort to improve the "boost out" control characteristics of the airplane. It is believed this program has been largely successful.

In general, results of the low speed analysis are presented for two control operating configurations; normal operating condition and emergency operating condition. Under normal operating conditions, calculations take into account the following conditions:

1. The control surfaces are actuated by an irreversible power system. There is no force feed-back from the control surfaces to the pilot.
2. The inboard and outboard elevons are inter-connected and act symmetrically as elevators and asymmetrically as ailerons.

3. Stick forces are simulated both longitudinally and laterally by a force feel device whose force output as measured at the top of the stick is $F_e = .009\,\delta_e\,q_c$ longitudinally, and $F_e = .0053\,\delta_{e_{\text{per side}}}\,q_c$ laterally. The effect of the gearing ratio is included in the constants .009 and .0053.

For emergency control operation, calculations were made using the following control characteristics and restrictions:

1. Primary longitudinal and lateral control obtained from outboard elevons only, which are connected directly to the stick. The inboard elevons are free floating.

2. Longitudinal and lateral stick forces are obtained from the aerodynamic hinge-moment of the outboard surfaces. The control stick has been lengthened to increase the gearing ratio, $\left(\frac{d\delta_e}{dx}\right)$, to .25 rad/ft. longitudinally and .40 rad/ft. laterally. The artificial force feel system is disconnected.

3. The longitudinal trimmer may be positioned to any angle between zero and 30° trailing edge up.

The estimated final center of gravity range is 22% MAC maximum forward and 25% MAC maximum aft. When applicable, calculations have been made for these two C.G. positions.

A summary of the high speed stability and control characteristics will be presented in the forthcoming Part II of this report.

5.0 PHYSICAL CHARACTERISTICS OF MODEL XF4D-1

The Douglas Model XF4D-1 is a single place, low aspect ratio, swept-wing, tailless, interceptor type airplane powered by a Westinghouse XJ40-WE-8 jet engine equipped for afterburning. Primary longitudinal and lateral control is accomplished by use of differentially acting elevons located along the trailing edge of either wing. Additional longitudinal control may be obtained from trimmers located inboard of the elevons. Directional stability and control is obtained from a single vertical surface lying in the plane of symmetry. An extendable slat is located along the leading edge of the wing to improve stall characteristics and increase maximum lift. Due to the unusually large angles of attack required for take-off and landing, a tail wheel is added to the tricycle type under-carriage.

Diagrams of the XF4D-1 three-view layout, wing, and vertical tail are shown in Figures 1,2and 3, and its physical dimensions are given in Table 1.

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FIG. 1

THREE-VIEW DIAGRAM OF DOUGLAS MODEL XF4D-1

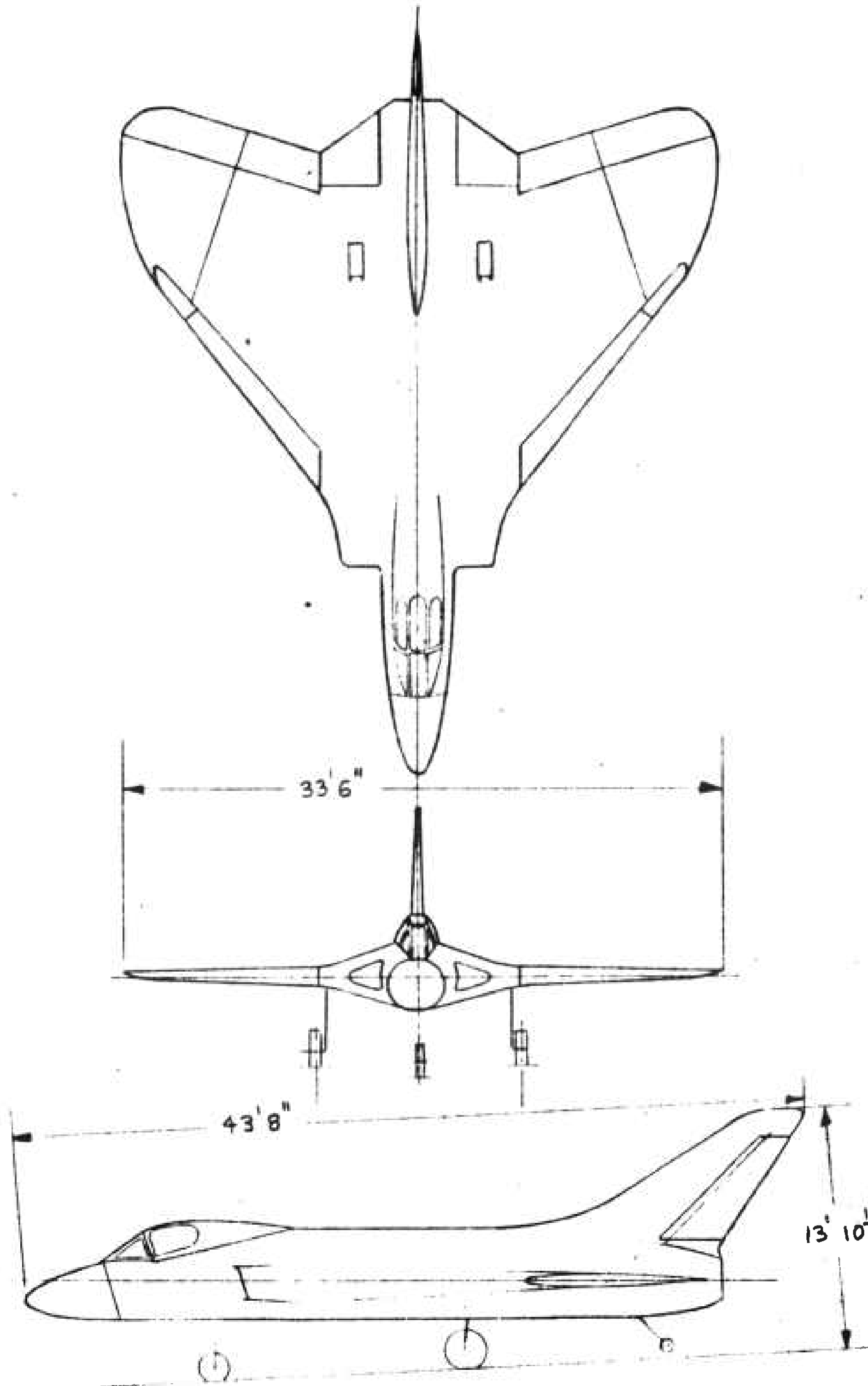

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FIG. 2

MODEL XF4D-1
WING DIAGRAM

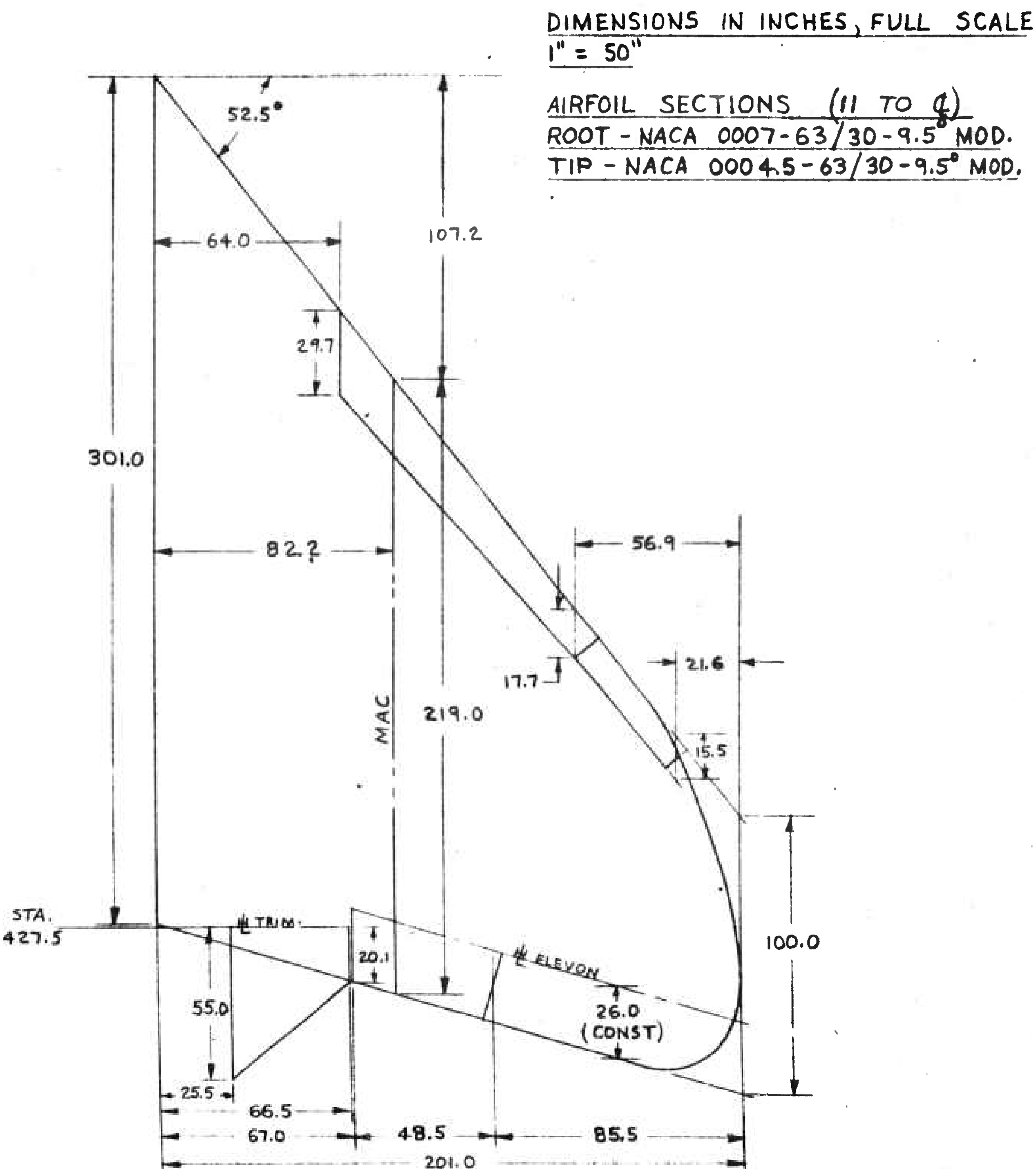

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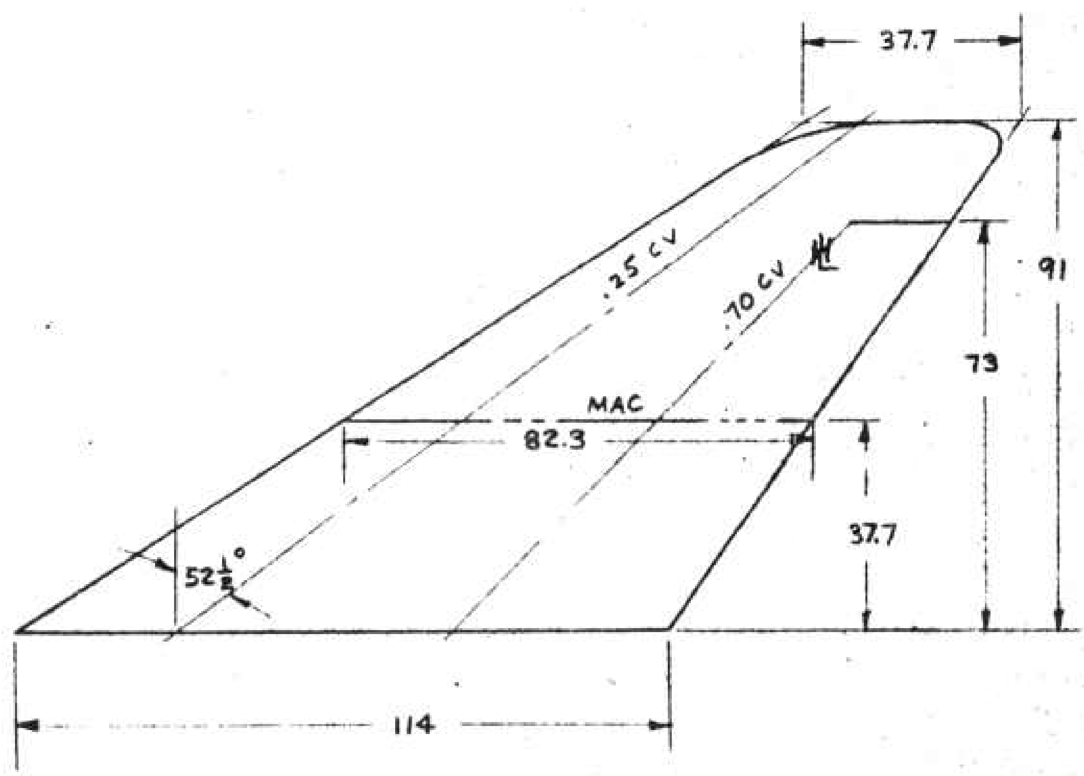
FIG. 3

MODEL XF4D-1

VERTICAL TAIL DIAGRAM

DIMENSIONS IN INCHES FULL SCALE

AIRFOIL SECTIONS: (// TO ℄)
ROOT - NACA 0008-63-30-9°
TIP - NACA 0006-63-30-6°45'



SCALE: 1" = 32"

TABLE 1

PHYSICAL CHARACTERISTICS OF DOUGLAS MODEL XF4D-1

Component Part	Units	Dimension
Engine		Westinghouse XJ40 - WE - 8
Wing		
Airfoil Designation		
Root Section		NACA 0007-63/30 - 9.5° Mod.
Tip Section		NACA 0004.5-63/30 - 9.5° Mod.
Area	sq.ft.	557
Span	ft.	33.5
Aspect Ratio	--	2.02
Taper Ratio	--	.332
MAC	ft.	18.25
Dist to MAC	ft.	6.85
Sweepback of LE.	deg.	52.5
Dihedral	deg.	0
Twist	deg.	0
Lift Increasing Device		
Nose Slats		
Type		Automatic
Span	$\%b_w$	54.2
Chord (Parallel to FRL)	$\%c_w$	12.68
Longitudinal and Lateral Control Devices		
Elevons		
Inboard + Outboard		
Area Aft ℄ (one side)	sq.ft.	22.57
Root Mean Square Chord	ft.	2.07
Span (percent Wing Span)	$\%b_w$	66.7
Deflection (Perpendicular to ℄)		
Pitch	deg.	15° Up to 10° Down
Lateral	deg.	± 20
Inboard		
Area Aft ℄ (one side)	sq.ft.	8.76
Root Mean Square Chord	ft.	2.16
Span (percent Wing Span)	$\%b_w$	24.2
Outboard		
Area Aft ℄ (one side)	sq.ft.	13.81
Root Mean Square Chord	ft.	2.01
Span (percent Wing Span)	$\%b_w$	42.5

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TABLE 1 (Cont'd)

Component Part	Units	Dimension
Longitudinal Trimmer		
Area Aft ℄ (one side)	sq.ft.	10.7
Root Mean Square Chord	ft.	3.24
Span (percent Wing Span)	$\%b_w$	20.4
Deflection (Perpendicular to Hinge Line)	deg.	0, -30
Vertical Surface		
Airfoil Designation		
Root Section		NACA 0008 - 63/30 - 9°
Tip Section		NACA 0006 - 63/30 - 6°45'
Area	sq.ft.	47.7
Span	ft.	7.58
Aspect Ratio	--	1.20
Taper Ratio	--	.331
MAC	ft.	6.86
Tail Length ($0.25\ t_w - 0.25\ t_v$)	ft.	13.51
Rudder		
Area	sq.ft.	12.7
Span	ft.	6.08
Root Mean Square Chord	ft.	2.18
Deflection (Parallel to FRL)	deg.	± 25
Gearing Ratios (Stick length to center of hand = 10" normal & 18" emergency)		
Elevons		
Longitudinal		
Normal	rad./ft.	.449
Emergency	rad./ft.	.25
Lateral		
Normal	rad./ft.	.718
Emergency	rad./ft.	.400
Rudder		
Normal	rad./ft.	1.7

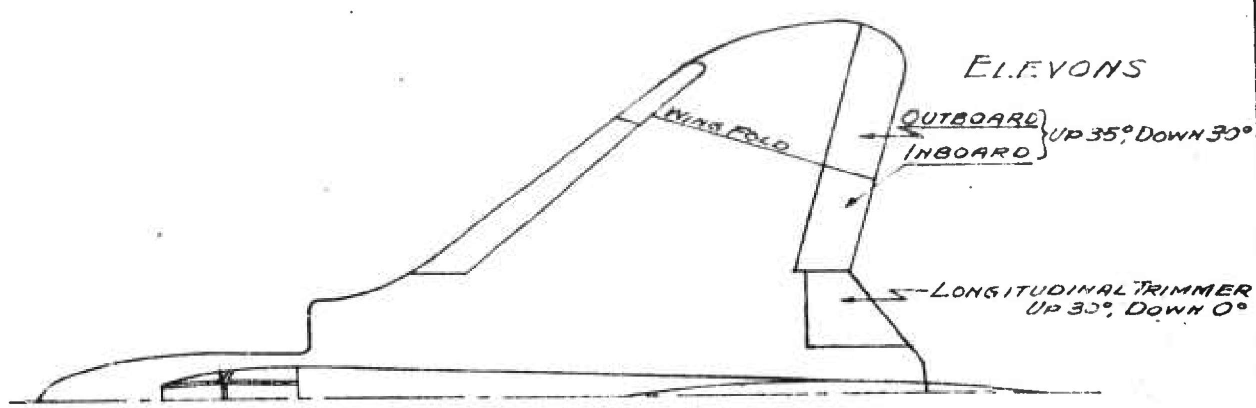
6.0 CONTROL SYSTEM DESIGN CHARACTERISTICS

6.1 General Description

Longitudinal and lateral control are accomplished by elevons which travel $\pm 20^{\circ}$ as ailerons and 15° up and 10° down as elevators. In addition, a trimmer is provided inboard of the elevons for the purpose of increasing longitudinal control in a normal take-off or landing and furnishing a means of emergency longitudinal trim.

Elevon actuation may be obtained in three ways. Under normal conditions the elevons are operated by an irreversible hydraulic power system that is independent of the airplane's hydraulic system and is so designed that an average rate of control deflection of 50 degrees per second may be obtained. If the power source of this independent hydraulic system fails, the aircraft's hydraulic system will supply power for control actuation, but at an average rate of only 20 degrees per second. Should all hydraulic power available for control actuation fail, a manual control system is available. In this case the pilot is connected directly to the outboard control surfaces (which may be used for both lateral and longitudinal control), but the inboard elevons are free to float.

The general arrangement of the controls is shown by the sketch below.

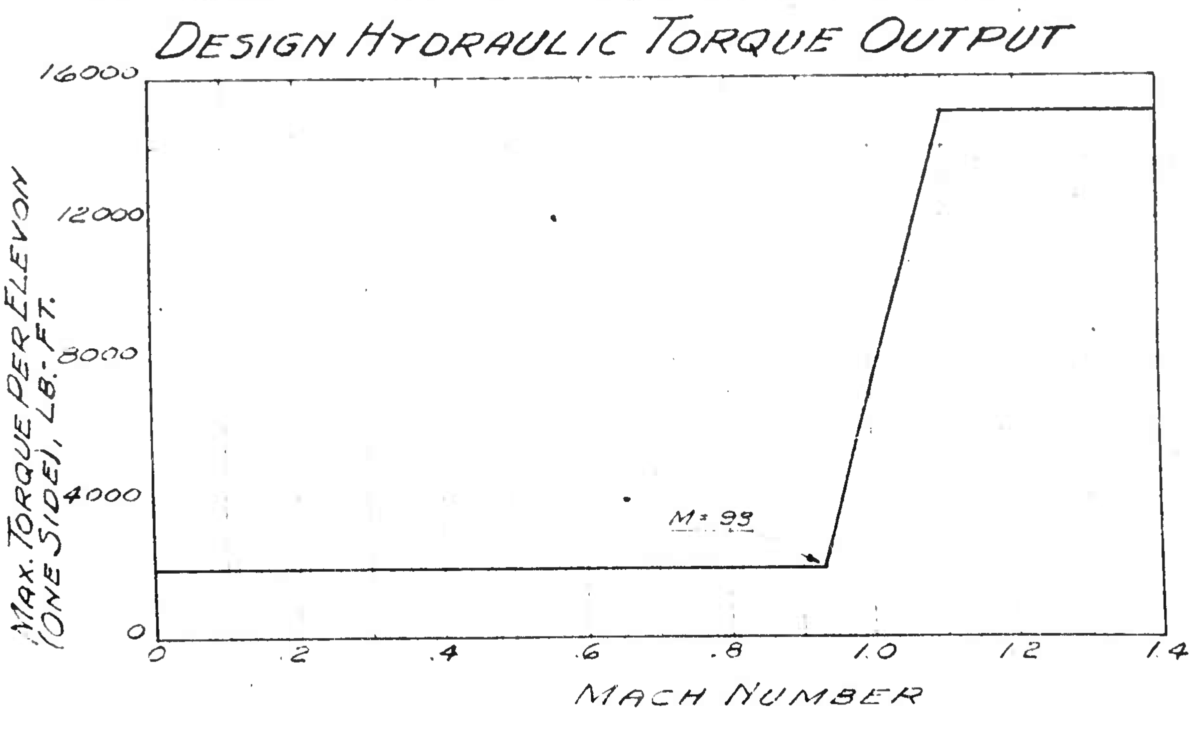


6.2 Normal Operating Characteristics

Normally the elevons act together symmetrically for elevator control and asymmetrically for lateral control. The elevons are actuated by hydraulic power units with no feed-back of aerodynamic forces to the pilot. Artificial feel will be provided by a device arranged to provide forces approximately proportional to stick displacement. The constant of proportionality between stick force and stick displacement will vary approximately with dynamic pressure up to a value of "q" corresponding to about M = .9 at S.L. From this "q" to higher values the stick force gradient will remain constant. Trim will be accomplished by adjusting the force-feel system to zero stick force.

The longitudinal trimmer provides additional control for take-off and landing under normal operation, to increase the load factor that can be attained at high altitudes, and to serve as an emergency pull-out device if the power system fails in a dive. The trimmer is to be used also for longitudinal stick-force trim when operating on manual control. The trimmer will be actuated by a separate lever in the cockpit and can be positioned when the landing gear is down or the hydraulic power system is inoperative. If the hydraulic system is operating with the gear retracted, the trimmer will return to neutral upon release of its control. The purpose of this type of control is to prevent the trimmer and elevons from being operated against each other in normal flight.

Lateral stick force also will be proportional to elevon displacement and q. The maximum elevon displacement will be limited by the hydraulic pressure which will be a function of Mach number as shown below.



This hydraulic pressure variation has been so chosen that the maximum elevon angle never exceeds the maximum allowable elevon angle, considering the structural strength of the wing in torque. Consequently the maximum deflection of the elevons as ailerons is a function of the deflection of the elevons as elevators. At a load factor of 6 and high indicated speeds the maximum aileron angle is less than at a load factor of one.

6.3 Emergency Control Operation

The change-over from power operation of the control surfaces to manual control will be automatic in the case of a hydraulic power failure. Immediately after failure, providing the hinge moment is above a selected value, the control surface will remain irreversible because the fluid in the elevon actuating cylinders will be trapped, (neglecting leakage throughout the system), by a check valve. The force-feel system is automatically disconnected at the time of hydraulic power failure. If the hinge moment of the elevon is reduced below this selected value, the check valve will open and automatically free the inner elevons. The outer elevons are still directly connected to the stick. In order to increase the mechanical advantage of the gearing system, means are provided for lengthening the control stick. For training purposes or if a failure occurs that allows the fluid in the cylinder to move freely, the pilot has a switch to shut off the hydraulic system and place him im manual control as above.

7.0 CENTER OF GRAVITY TRENDS

Since the XF4D-1 is now in the process of design, it is impossible to predict accurately the final maximum forward and aft center of gravity limits. Previous analysis has shown that the difference between the maximum forward C.G. with gear and slats extended and the maximum aft C.G. with gear and slats retracted is 3% MAC. Using this difference as a base, it is believed the final center of gravity range for the conditions specified will be near 22% MAC to 25% MAC. Calculations in this report are based on this assumption.

As further discussion will indicate, it will be necessary to restrict the center of gravity range to the values mentioned above. If final weight and balance figures reveal the C.G. travel to be farther forward or aft along the mean aerodynamic chord, ballast will have to be used to bring the limits into the desired range.

8.0 DISCUSSION

8.1 Longitudinal Characteristics

8.1.1 Static Longitudinal Stability

Trimmed, stick-fixed neutral points versus lift coefficient are shown in Figure 4. At all speeds below which Mach number effects are negligible the neutral point is aft of 30% MAC. Since the maximum aft center of gravity position has been set at 25% MAC, the static margin requirement of Reference 4 is met over the low speed flight range.

8.1.2 Dynamic Longitudinal Stability

Since the XF4D-1 airplane has no horizontal tail, it was expected that damping of the longitudinal oscillations would be low compared with conventional airplanes. Calculations were made, (Reference 5), that verified these expectations. Several changes in airplane configuration and inertia characteristics have been made since Reference 5 was published that directly effect longitudinal damping. These changes are an increased fuselage nose length, which reduces $\frac{dc_m}{d\alpha}$, and an increased moment of inertia in pitch. New calculations have been made using data obtained from wind tunnel tests of the latest configuration. Table 2 lists the mass and aerodynamic parameters used in the analysis.

TABLE 2

SUMMARY OF PARAMETERS USED IN DYNAMIC LONGITUDINAL STABILITY CALCULATIONS

C_L	.550	.275	.150	.071
Gross Weight, Lbs	16821	16821	16821	16821
Inertia in Pitch (Slug Ft.^{2})	31500	31500	31500	31500
C_{m_q}	-.50	-.50	-.50	-.50
C_{L_α} (per Rad.)	2.61	2.61	2.61	2.61
C_{m_α} (per Rad.)	-.315	-.229	-.143	-.129

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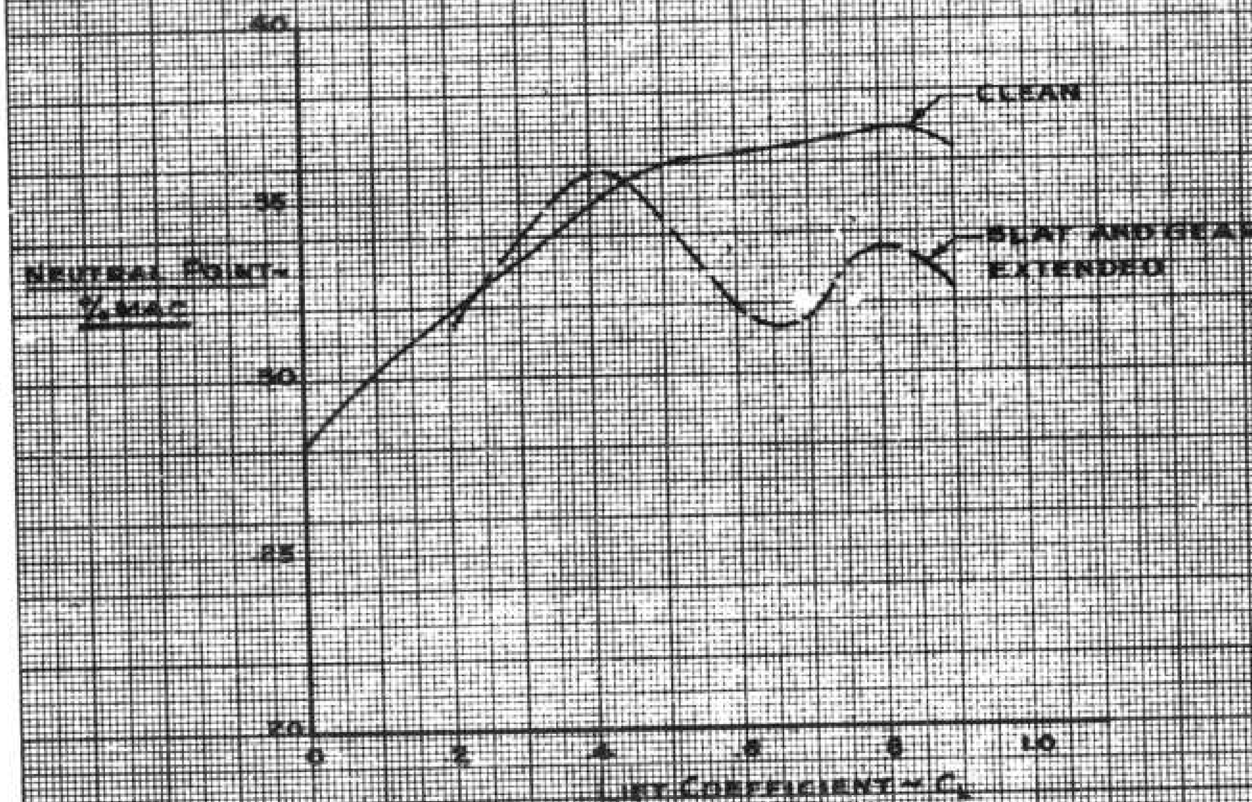
Model XF4D-1

Report No. ES 15304

MODEL XF4D-1

STICK FIXED NEUTRAL POINTS VS LIFT COEFFICIENT



A summary of the damping characteristics is presented in Figure 5. This graph was plotted with α and β as coordinates to permit showing the relative value of the damping of the oscillation by drawing lines corresponding to the time required for the oscillation to decay to 1/2 or 1/10 the initial value. Damping is marginal for all lift coefficients at sea level, and becomes worse as altitude increases, though the airplane will always damp to 1/2 amplitude in one cycle or less.

It is doubtful if any aerodynamic means can be found to substantially increase damping in pitch. Reference 3 points out that it is impossible to change C_{m_α}, C_{m_q}, or the inertia in pitch enough to materially improve the situation. Should flight tests verify the low damping, use of a rate-gyro, actuating the elevons to oppose the short period longitudinal oscillation, seems to be the logical solution.

8.1.3 Longitudinal Control

8.1.3.1 Normal Control Configuration

8.1.3.1.1 Maximum Lift Characteristics

The final configuration of model XF4D-1 is equipped with 26" chord elevons from which primary pitch control is obtained. Pitch control may be augmented when necessary, such as during take-off and landing, by longitudinal trimmers located inboard of the elevons. Since preliminary design of the airplane had 40" chord elevons, the maximum lift coefficient to which the airplane can be trimmed in normal flight, (trimmers faired), is lower than the values quoted in previous reports.

Figure 6 shows trimmed lift curves and δ_e versus C_L for two center of gravity positions. The airplane is clean and operating in a region of no ground effect. Under these conditions the trimmer setting is zero degrees.

When the gear is down, the pilot can position the trimmer to any angle between zero and 30 degrees trailing edge up. Figure 7 shows trimmed lift curves and C_L versus δ_e for the trimmer fully deflected andfaired. Gear and slats are extended and there is no ground effect.

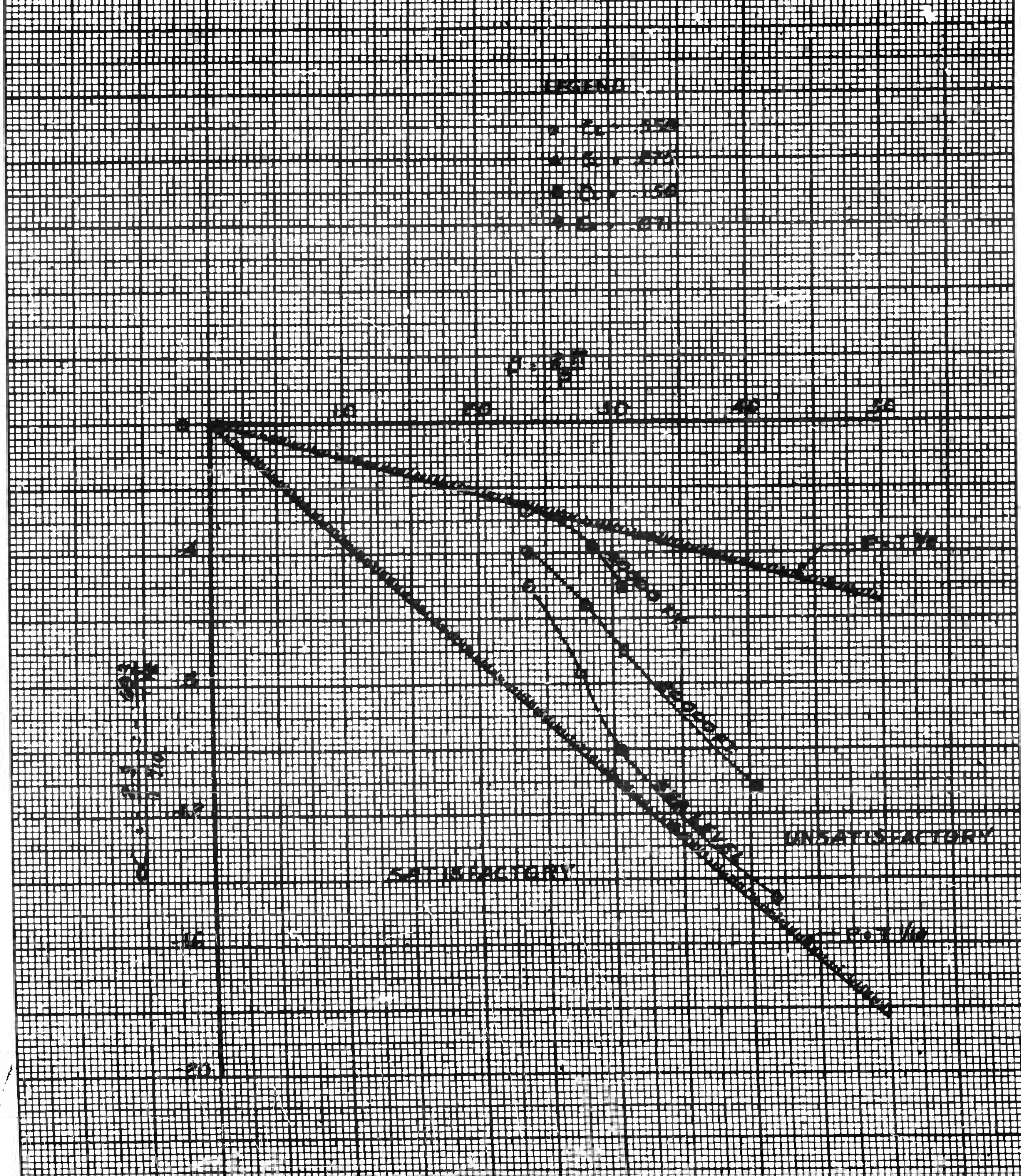
During take-off and landing, the trimmer should be fully deflected to obtain minimum take-off and landing speeds. Curves of trimmed C_L versus α and δ_e are shown in Figure 8. These include ground effect.

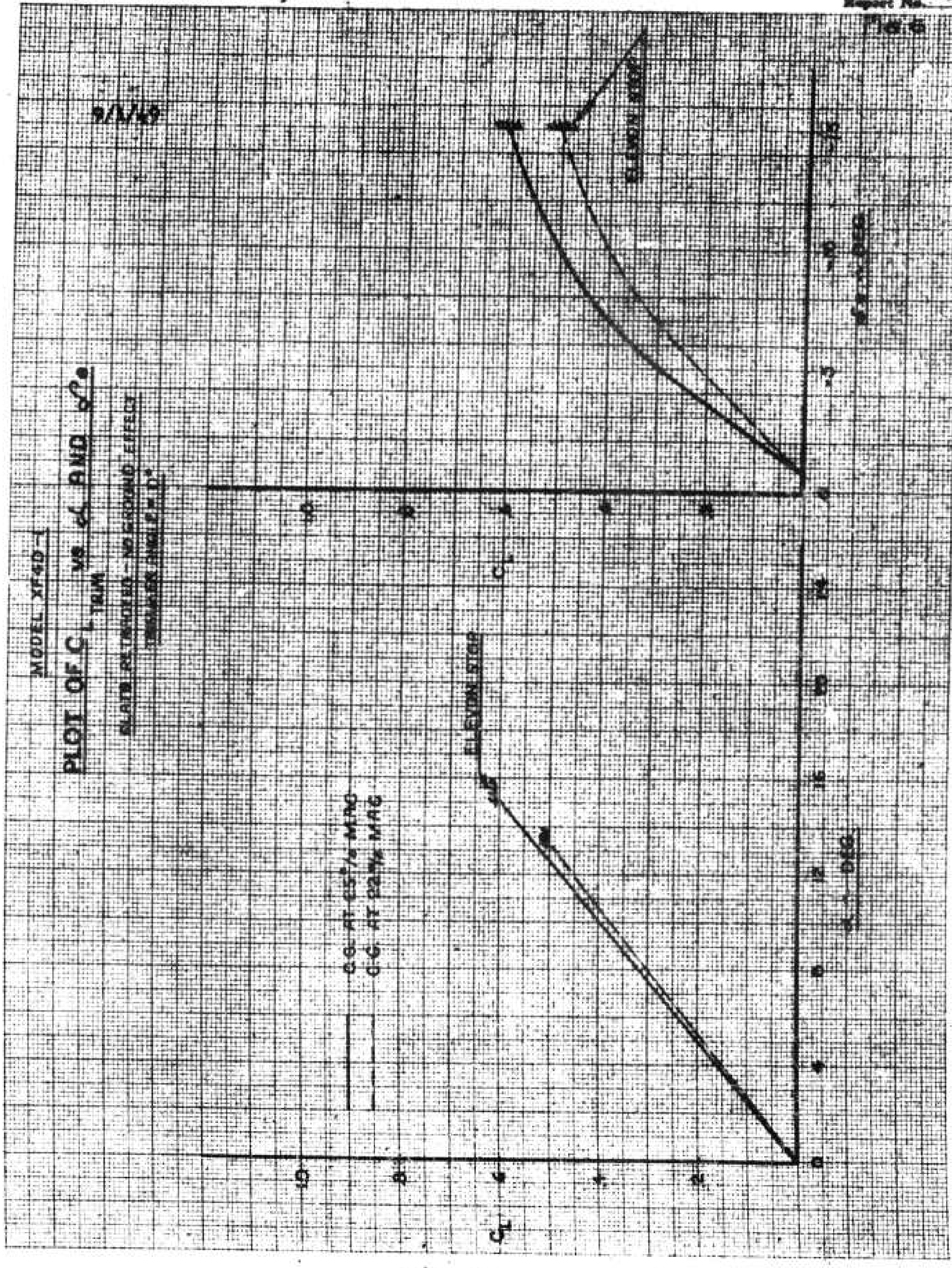
Maximum trimmed lift coefficients for the above mentioned condition are summarized in the following table.

MODEL XF4D-1

FIG. 5

DAMPING OF THE "SHORT PERIOD" LONGITUDINAL OSCILLATION

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MODEL XF4D-1
PLOT OF $C_{L_{TRIM}}$ VS α AND δ_e
SLATS RETRACTED - NO GROUND EFFECT
ELEVON STOP
ELEVON STOP
C.G. AT 25% MAC
C.G. AT 22% MAC
α - DEG
C_L
C_L

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Model XF4D-1

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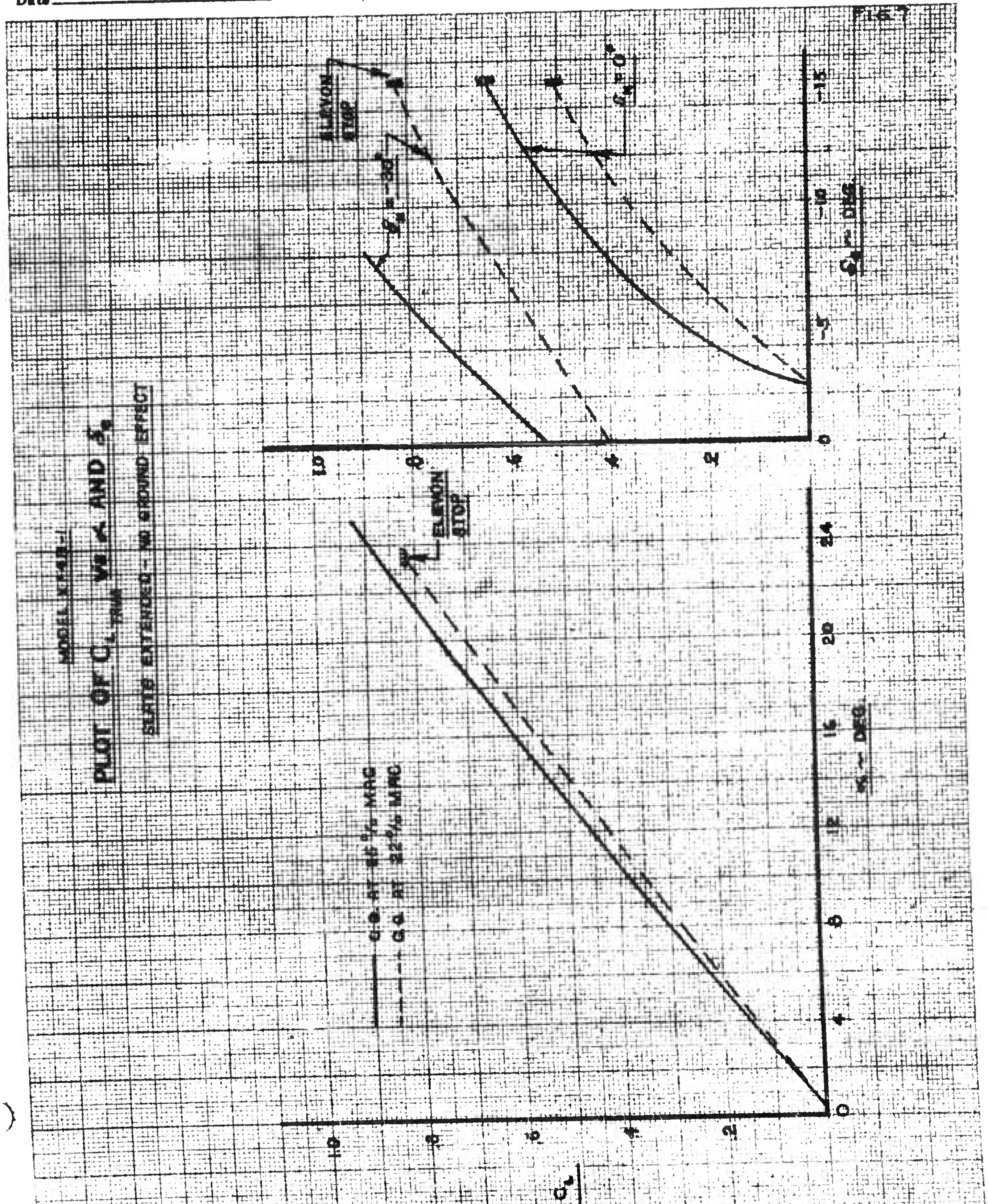

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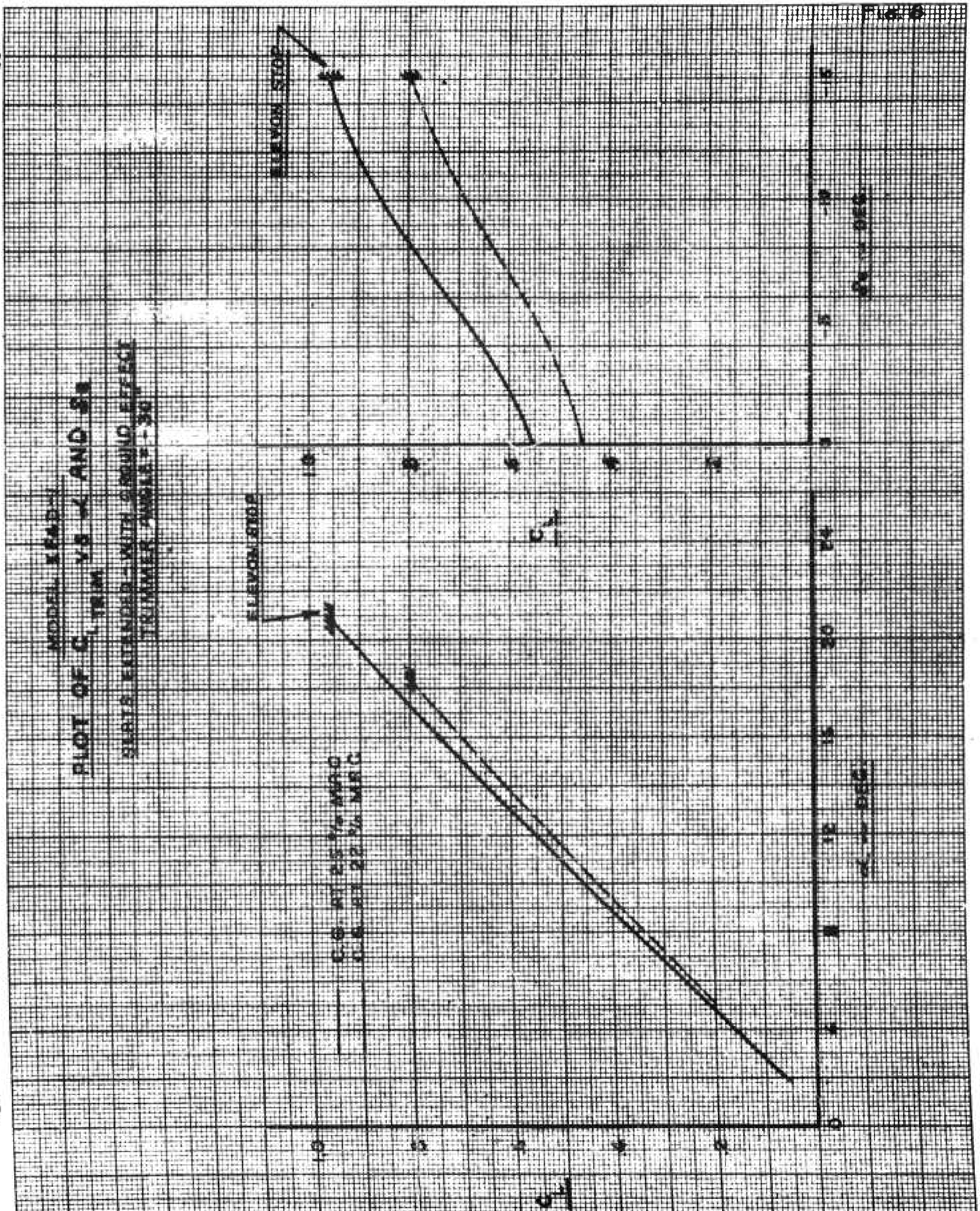

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TABLE 3

Flight Condition and Airplane Configuration	Maximum Trimmed C_L	
	CG=25% MAC	CG=22% MAC
Slats and Gear Retracted, No Ground Effect, $\delta_e = -15^\circ$, $\delta_N = 0^\circ$	.610	.506
Slats and Gear Extended, No Ground Effect, $\delta_e = -15^\circ$, $\delta_N = 0^\circ$	.647	.510
Slats and Gear Extended, No Ground Effect, $\delta_e = -15^\circ$, $\delta_N = -30^\circ$	---	.830
Slats and Gear Extended in Presence of Ground, $\delta_e = -15^\circ$, $\delta_N = -30^\circ$	.955	.795

Maximum lift coefficient and angle of attack obtained in presence of the ground is shown in Figure 9 as a function of center of gravity position.

8.1.3.1.2 Effect of Trimmer Position on Elevon Position and Stick Forces Required for Landing

Elevon position and stick force required to trim versus indicated air speed are shown for two trimmer positions in Figures 10 and 11. For a given speed, increasing the trimmer deflection requires reducing the elevon deflection to maintain trim. Thus, minimum landing speeds are obtained when the trimmer is fully up. The slope of the elevon angle versus indicated airspeed curve is stable, an up deflection being required to reduce speed, and thus satisfies stick fixed static stability requirements.

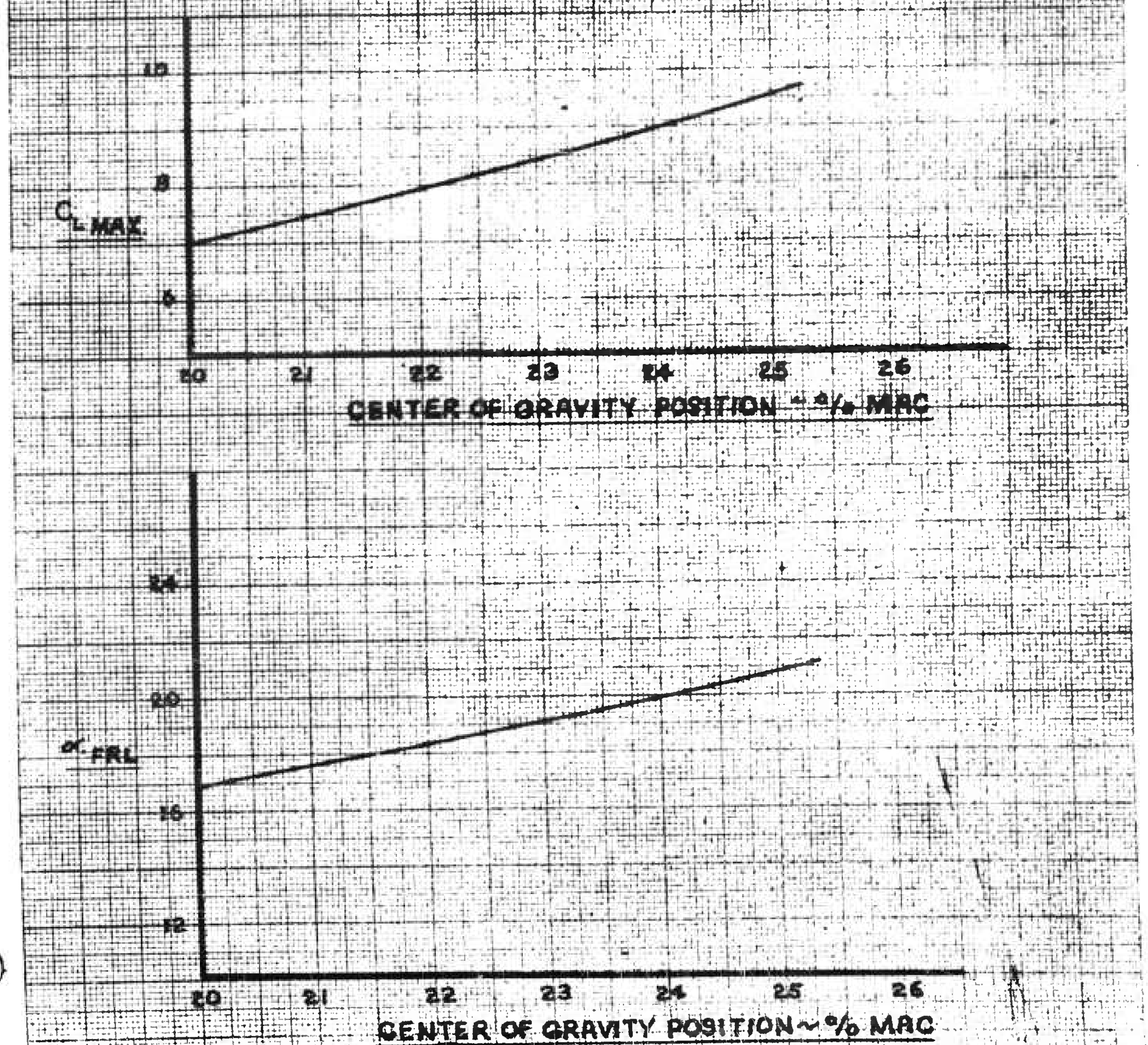
Stick forces associated with various elevon positions are supplied by a device giving forces proportional to dynamic pressure and elevon deflection. Force trim is accomplished by altering the zero force position of the stick until zero force corresponds to the stick position required for trim. The angle at which the trimmer is set will have little effect on stick force required to trim provided the force is reduced to zero at the same airspeed for various trimmer angles. This may be explained by the fact that no matter where the trimmer is set, if the trim force is reduced to zero at a constant speed, the amount of change of elevon deflection required to produce a given speed change is essentially constant. In Figures10 and 11 the force is trimmed to zero at 1.4 times the stalling speed for both trimmer deflections shown.

FIG. 9

MODEL XF4D-1

MAXIMUM LIFT COEFFICIENT AND ANGLE OF ATTACK VERSUS CENTER OF GRAVITY POSITION

ELEVON ANGLE = -15°
TRIMMER ANGLE = -30°
SLATS EXTENDED



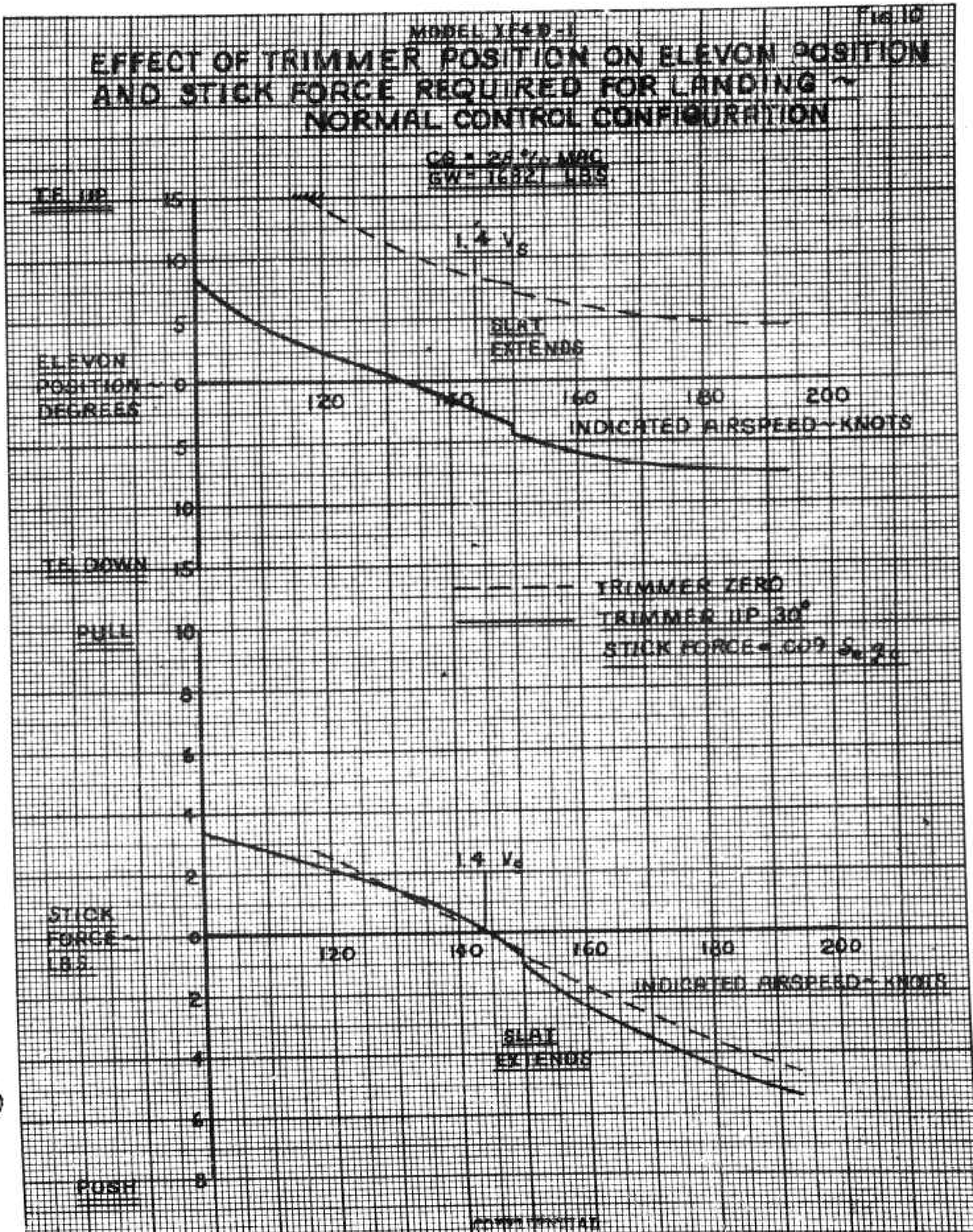
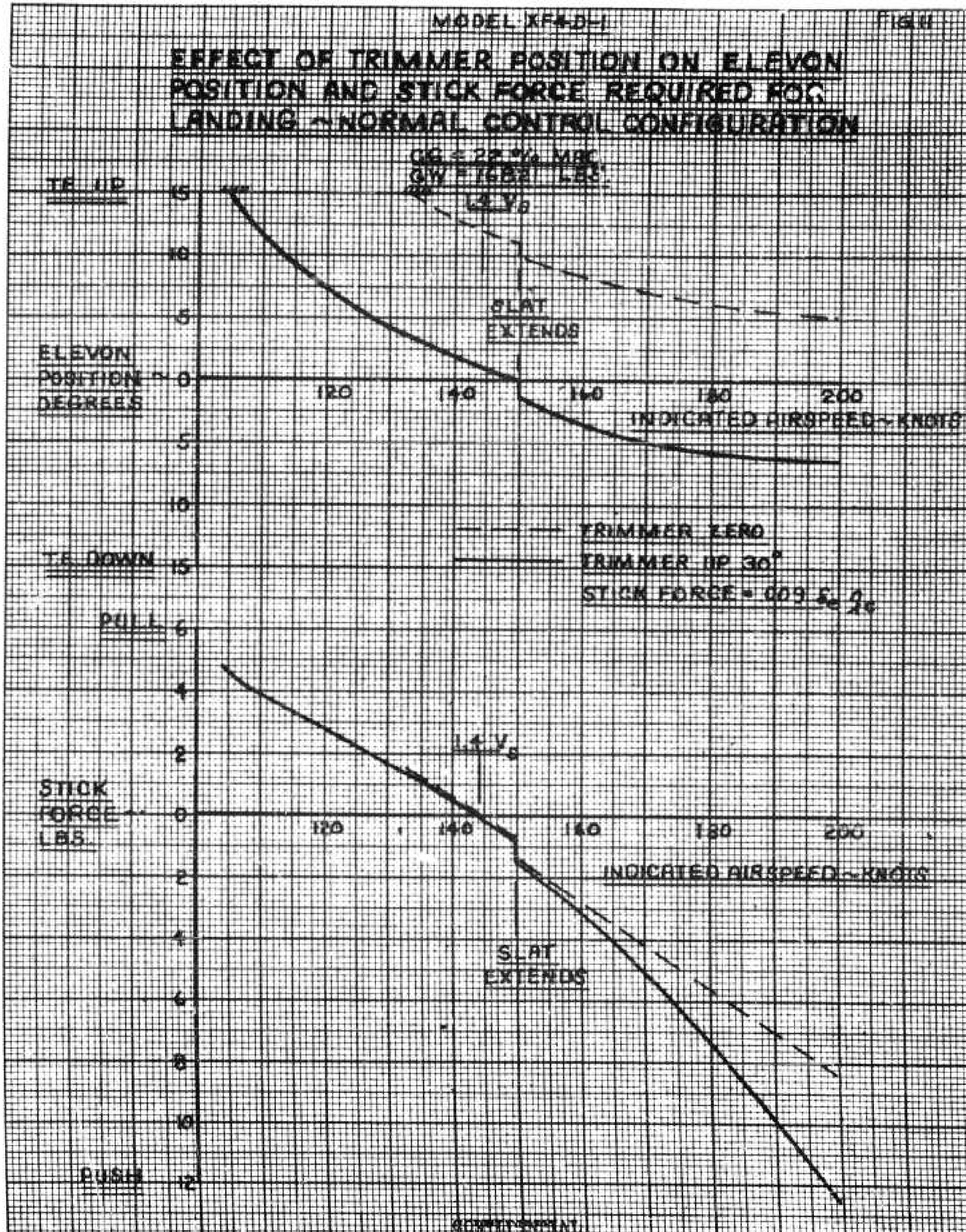


FIG 10
MODEL XF4D-1
EFFECT OF TRIMMER POSITION ON ELEVON POSITION AND STICK FORCE REQUIRED FOR LANDING ~ NORMAL CONTROL CONFIGURATION
GW = 16821 LBS
T.E. UP
T.E. DOWN
ELEVON POSITION ~ DEGREES
1.4 V_s
SLAT EXTENDS
INDICATED AIRSPEED ~ KNOTS
120
140
160
180
200
TRIMMER ZERO
TRIMMER UP 30°
STICK FORCE = .009
PULL
PUSH
STICK FORCE ~ LBS.


MODEL XF4D-1
FIG 11
EFFECT OF TRIMMER POSITION ON ELEVON POSITION AND STICK FORCE REQUIRED FOR LANDING ~ NORMAL CONTROL CONFIGURATION
T.E. UP
T.E. DOWN
ELEVON POSITION ~ DEGREES
15
10
5
0
5
10
15
120
140
160
180
200
INDICATED AIRSPEED ~ KNOTS
SLAT EXTENDS
TRIMMER ZERO
TRIMMER UP 30°
STICK FORCE = .009 δ_e q_c
PULL
PUSH
STICK FORCE ~ LBS.
6
4
2
0
2
4
6
8
10
12
120
140
160
180
200
INDICATED AIRSPEED ~ KNOTS
SLAT EXTENDS

Since it is necessary to have reasonable stick force characteristics at high speeds, the landing forces are light because of low values of q.

A curve of elevon angle required to hold the airplane off the ground at 1.05 times the stalling speed versus center of gravity position is shown in Figure 12. The elevons are sufficiently powerful to meet the requirements of Reference 4 to a forward center of gravity position of 21.6% MAC.

8.1.3.1.3 Stick Force Characteristics During Accelerated Flight

Elevon position and stick force versus load factor for various lift coefficients are shown in Figures 13 and 14 for C.G. positions of 25% MAC and 22% MAC respectively. These curves were obtained assuming the trimmer was fully deflected at lift coefficients above .40 and was faired below C_L = .40.

The variation is stable and linear up to maximum elevon deflections but in excess of the requirements of Reference 4 over the low speed flight range. This is not considered objectionable since the maximum "g's" that can be pulled at low speeds are small and the corresponding stick forces reasonable. As speed increases, the stick force per "g" gradient decreases until the variation is within the specified limits around Mach number .40.

8.1.3.1.4 Nose Wheel Lift-Off Characteristics

Figure 15 shows the geometry of the landing gear of Model YF4D-1, which is composed of two main wheels, a nose wheel and a tail wheel. During nose wheel lift off the tail wheel contacts the ground before the nose wheel is off and must be compressed before further raising of the nose can be accomplished. Figure 16 presents speed at which the tail wheel will compress as a function of gross weight and center of gravity position.

After sufficient force has been applied to the tail wheel to start compression, the airplane must further increase speed to continue compression of the tail wheel and thus raise the nose wheel. Nose wheel lift-off speeds are shown in Figure 17 as a function of gross weight and center of gravity position.

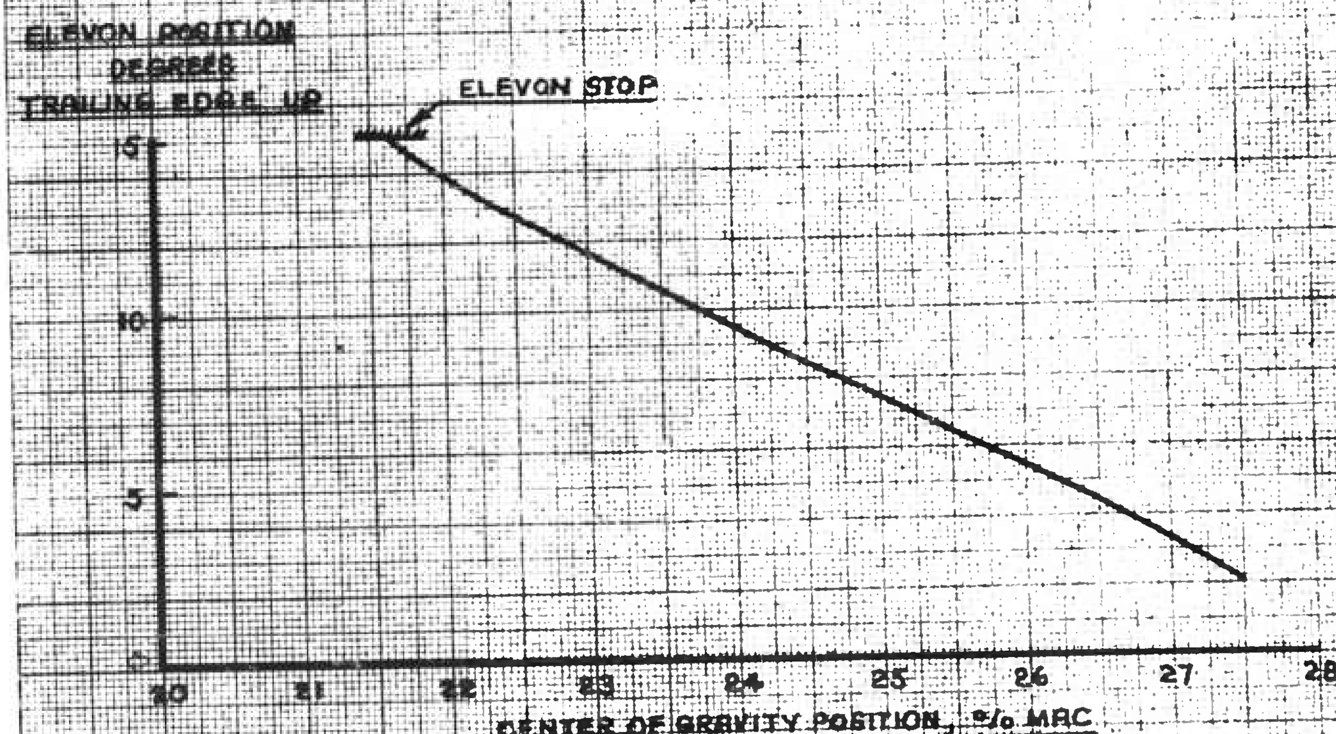
For a gross weight of 16821 lbs., the maximum forward center of gravity for which the nose wheel lift-off requirements of Reference 4 can be met is 23.8% MAC. It is possible that under certain loading conditions the center of gravity may be forward of 23.8% MAC for take-off. This is not considered to be serious for the following reason. For land take-offs, the maximum ground angle that can be

FIG. 12

MODEL XF4D-1

ELEVON POSITION REQUIRED TO HOLD AIRPLANE OFF GROUND AT 1.05 V_s VERSUS CENTER OF GRAVITY POSITION

TRIMMER ANGLE = 30° T.E. UP



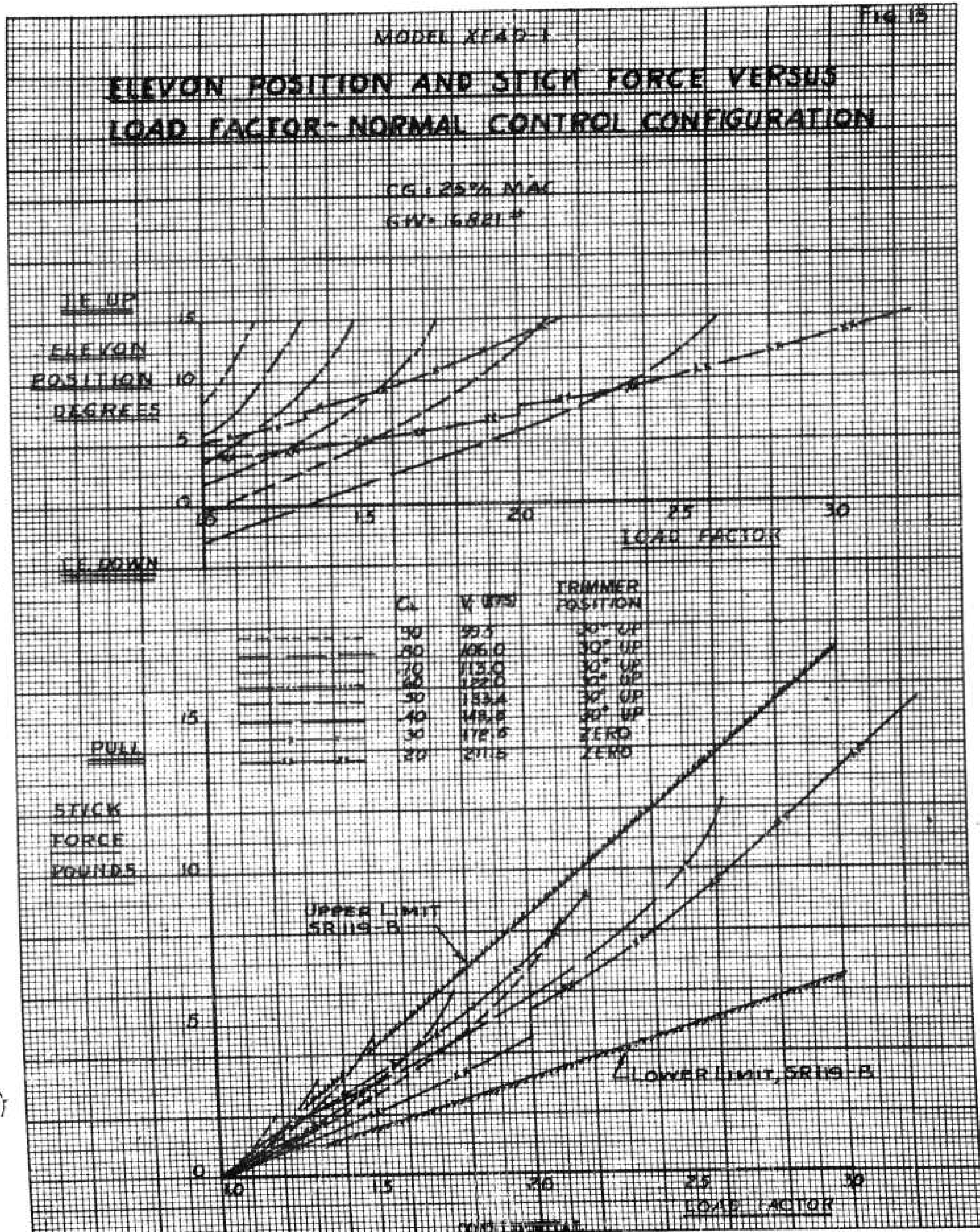


Fig 15
MODEL XF4D-1
ELEVON POSITION AND STICK FORCE VERSUS
LOAD FACTOR - NORMAL CONTROL CONFIGURATION
CG - 25% MAC
GW = 16821 #
TE UP
ELEVON
POSITION
DEGREES
TE DOWN
15
10
5
0
1.0
1.5
2.0
2.5
3.0
LOAD FACTOR
C_L
V (EAS)
TRIMMER POSITION
.90 99.5 30° UP
.80 106.0 30° UP
.70 113.0 30° UP
.60 122.0 30° UP
.50 133.4 30° UP
.40 148.8 30° UP
.30 172.6 ZERO
.20 211.6 ZERO
PULL
STICK
FORCE
POUNDS
UPPER LIMIT
SR119-B
LOWER LIMIT, SR119-B
LOAD FACTOR

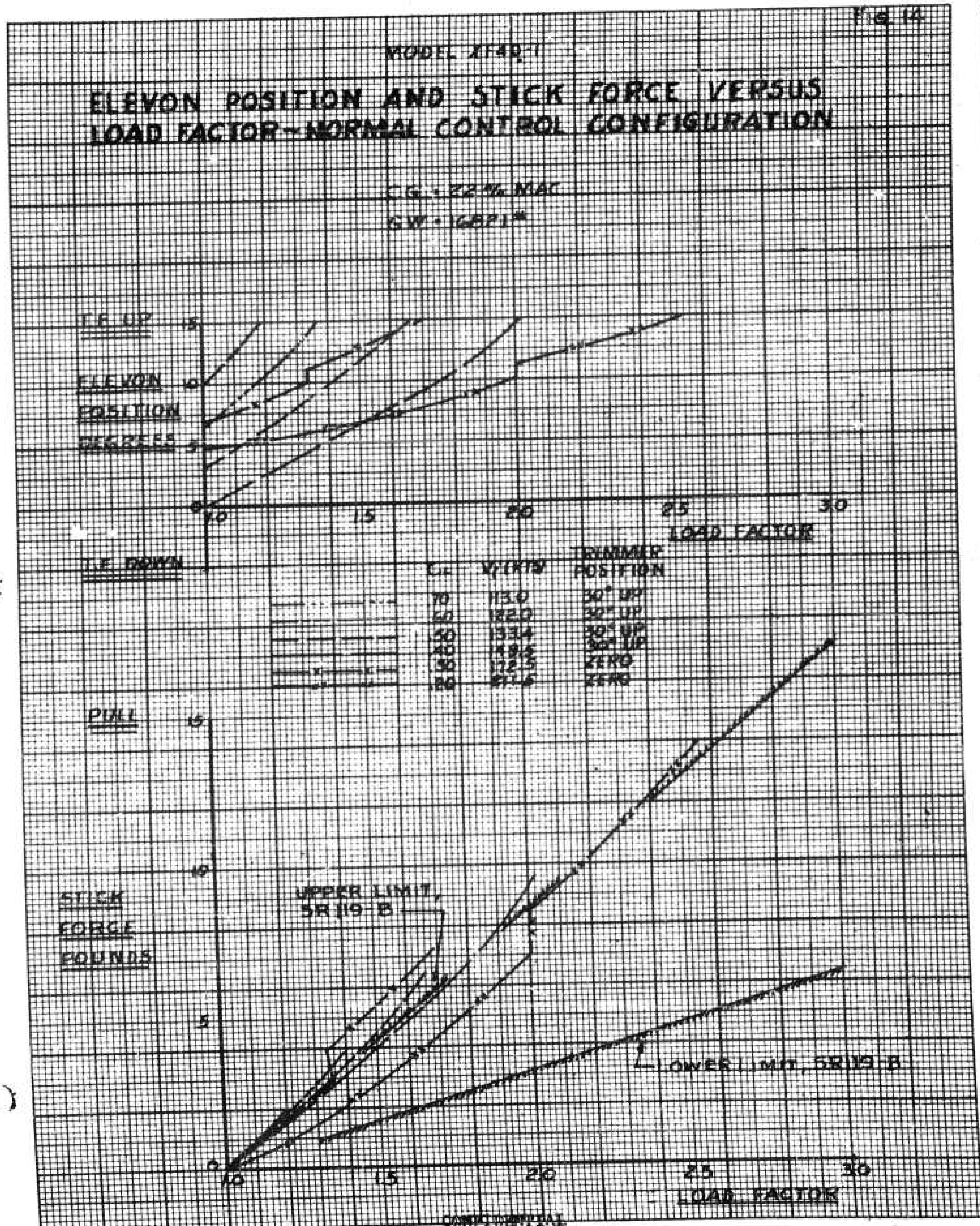
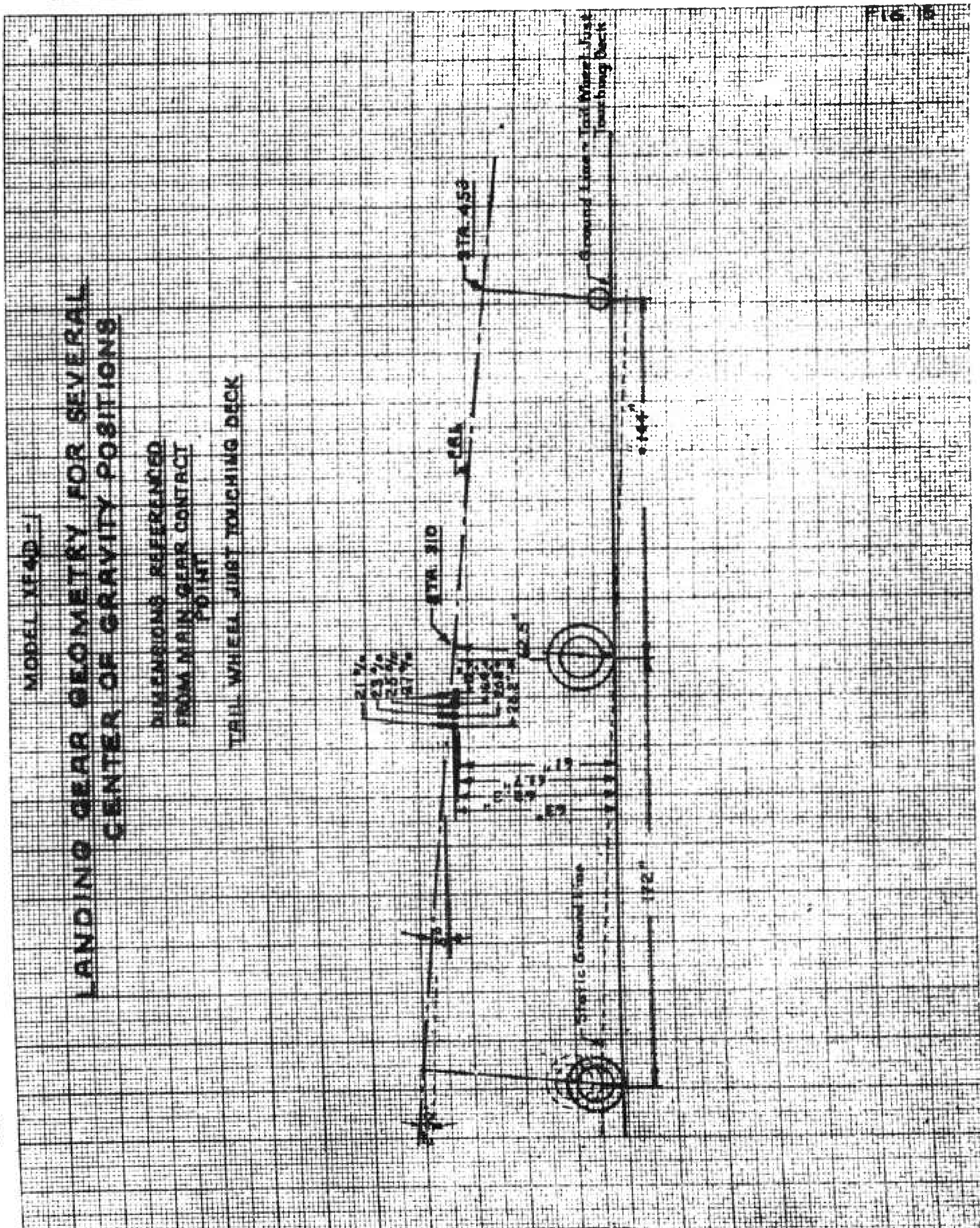


FIG. 14
MODEL XF4D-1
ELEVON POSITION AND STICK FORCE VERSUS
LOAD FACTOR - NORMAL CONTROL CONFIGURATION
C.G. - 22% MAC
G.W. - 16821#
T.E. UP
ELEVON
POSITION
DEGREES
T.E. DOWN
LOAD FACTOR
C_L
V_i (KTS)
TRIMMER POSITION
.70 113.0 30° UP
.60 122.0 30° UP
.50 133.4 30° UP
.40 30° UP
.30 172.5 ZERO
.20 ZERO
PULL
STICK
FORCE
POUNDS
UPPER LIMIT, SR 119-B
LOWER LIMIT, SR 119-B
LOAD FACTOR


MODEL XF4D-1
LANDING GEAR GEOMETRY FOR SEVERAL CENTER OF GRAVITY POSITIONS
DIMENSIONS REFERENCED FROM MAIN GEAR CONTACT POINT
TAIL WHEEL JUST TOUCHING DECK
STA. 453
STA. 210
Static Ground Line
172"
144"

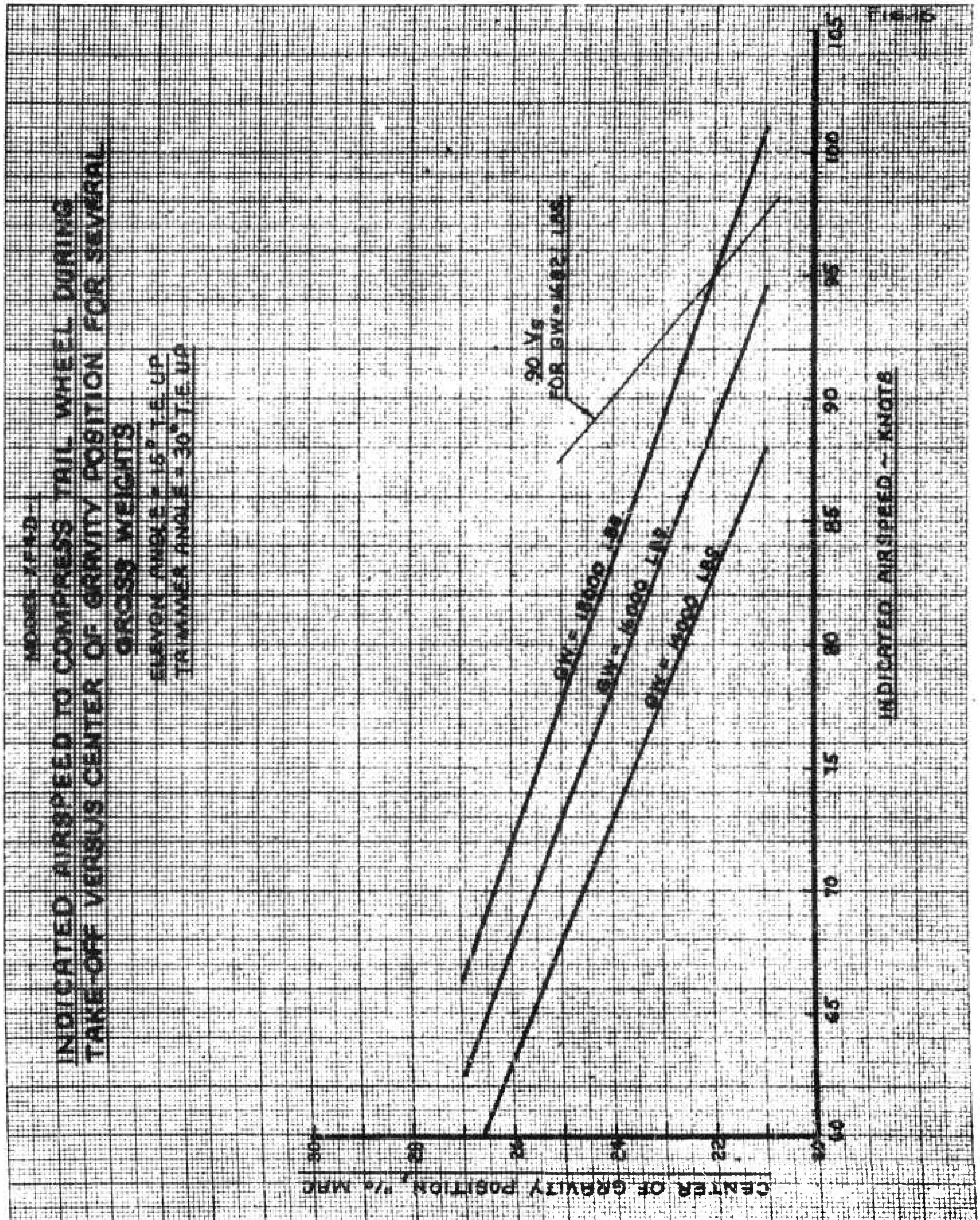
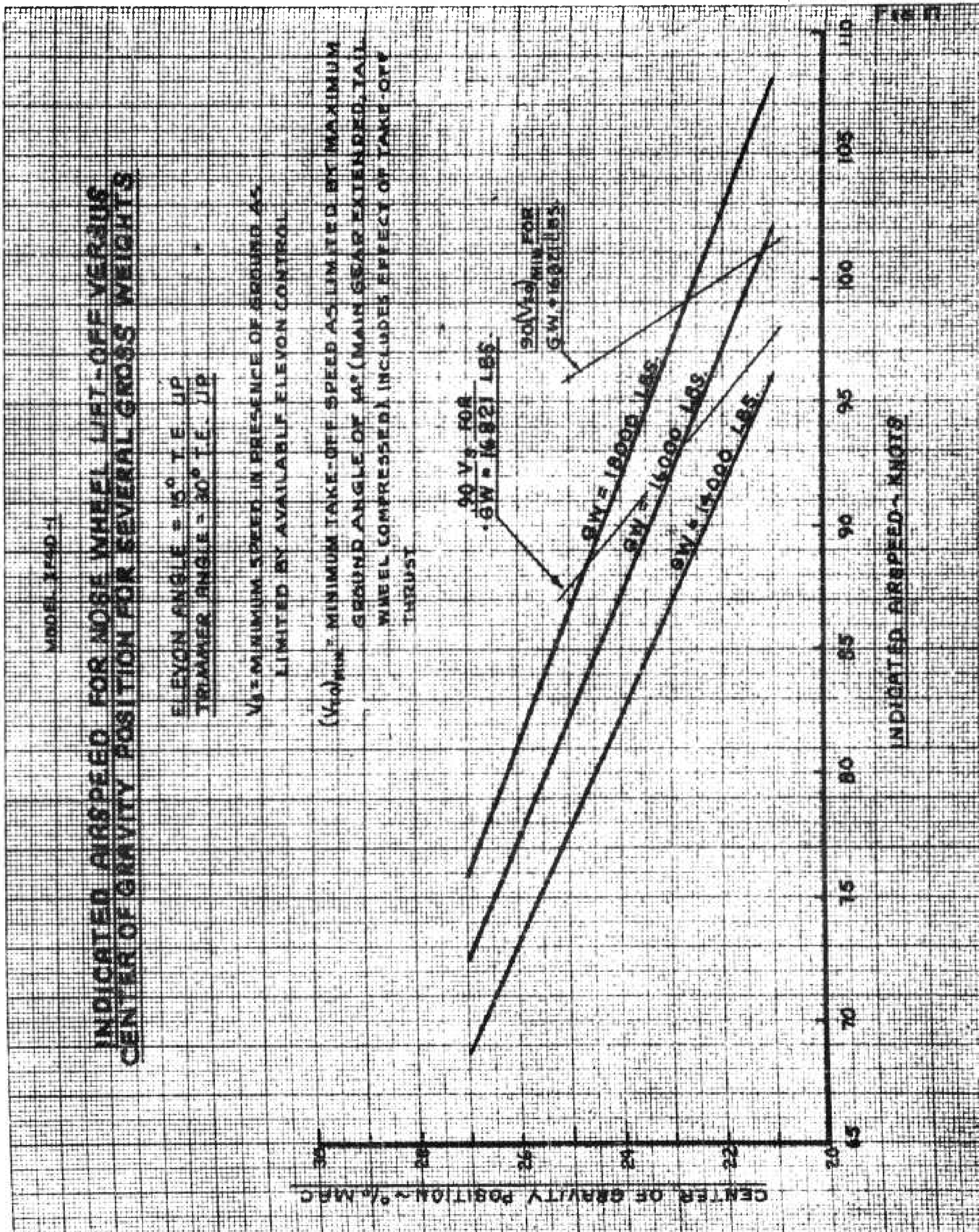


FIG. 15
MODEL XF4D-1
INDICATED AIRSPEED TO COMPRESS TAIL WHEEL DURING
TAKE-OFF VERSUS CENTER OF GRAVITY POSITION FOR SEVERAL
GROSS WEIGHTS
ELEVON ANGLE = 16° T.E. UP
TRIMMER ANGLE = 30° T.E. UP
GW = 18000 LBS.
GW = 16000 LBS.
GW = 14000 LBS.
90 Vs
INDICATED AIRSPEED – KNOTS
60
65
70
75
80
85
90
95
100
105
CENTER OF GRAVITY POSITION, % MAC
20
22
24
26
28
30


INDICATED AIRSPEED FOR NOSE WHEEL LIFT-OFF VERSUS
CENTER OF GRAVITY POSITION FOR SEVERAL GROSS WEIGHTS
MODEL XF4D-1
ELEVON ANGLE = 15° T.E. UP
TRIMMER ANGLE = 30° T.E. UP
V_S = MINIMUM SPEED IN PRESENCE OF GROUND AS LIMITED BY AVAILABLE ELEVON CONTROL
$(V_{T.O.})_{min}$ = MINIMUM TAKE-OFF SPEED AS LIMITED BY MAXIMUM GROUND ANGLE OF 14° (MAIN GEAR EXTENDED, TAIL WHEEL COMPRESSED) (INCLUDES EFFECT OF TAKE-OFF THRUST)
.90 V_S FOR GW = 16821 LBS.
.90 $(V_{T.O.})_{min}$ FOR GW = 16821 LBS.
GW = 18000 LBS.
GW = 16000 LBS.
GW = 14000 LBS.
INDICATED AIRSPEED ~ KNOTS
65
70
75
80
85
90
95
100
105
110
CENTER OF GRAVITY POSITION ~ % MAC
20
22
24
26
28
30

obtained during take-off is 14°. The important consideration is to be able to obtain an angle of attack of 14° at the speed required for take-off at that attitude. Assuming a gross weight of 16821 lbs., a center of gravity position of 22% MAC, and an angle of attack of 14°, the speed for take-off is 111 knots. Examination of Figure 17 shows that under the same conditions, the nose wheel can be lifted at 100 knots, or .90 times the minimum take-off speed. The discussion in this section assumes the elevons up 15°, and the trimmer up 30°.

8.1.3.1.5 Effect of Extending gear, Slats, and Dive Brakes on Longitudinal Trim

Due to the design of the synthetic force feel system, changes in stick force that accompany variations in airplane configuration are unusually small. Changes in elevon position and stick force required for trim when the gear and slats are extended are shown in Figure 18. The maximum change in stick force is of the order of one pound.

Extension of the dive brakes produces an aerodynamically symmetrical change in the airplane configuration. Trim changes due to extending the brakes are essentially zero as shown by the pitching moment versus lift curves of Figure 19.

8.1.3.2 Emergency Control Configurations

8.1.3.2.1 Characteristics Obtained During Change-Over from Power to Manual Operation of the Control Surfaces

8.1.3.2.1.1 General Characteristics of the Change-Over System

During power operation of the control surfaces, the inboard and outboard surfaces are interconnected by a locking mechanism held in place by the control system hydraulic pressure. If a hydraulic failure occurs during periods when excessive elevon hinge moments are required for trim, a check valve in the system traps and prevents the pressure holding the locking mechanism in place from being relieved unless the aerodynamic hinge moment of the control surface is relieved. The system is so designed that under this condition, the pilot is incapable of moving the control surfaces against the aerodynamic hinge moment but can, if he wishes, move the control surfaces toward their trail position to reduce the elevon hinge moments. If no control stick movement toward the elevon trail position is made by the pilot, the control surfaces will remain at the position occupied at the time of power failure.

The pressure holding the elevon interconnecting mechanism in place is a function of elevon hinge moment. As soon as the hinge

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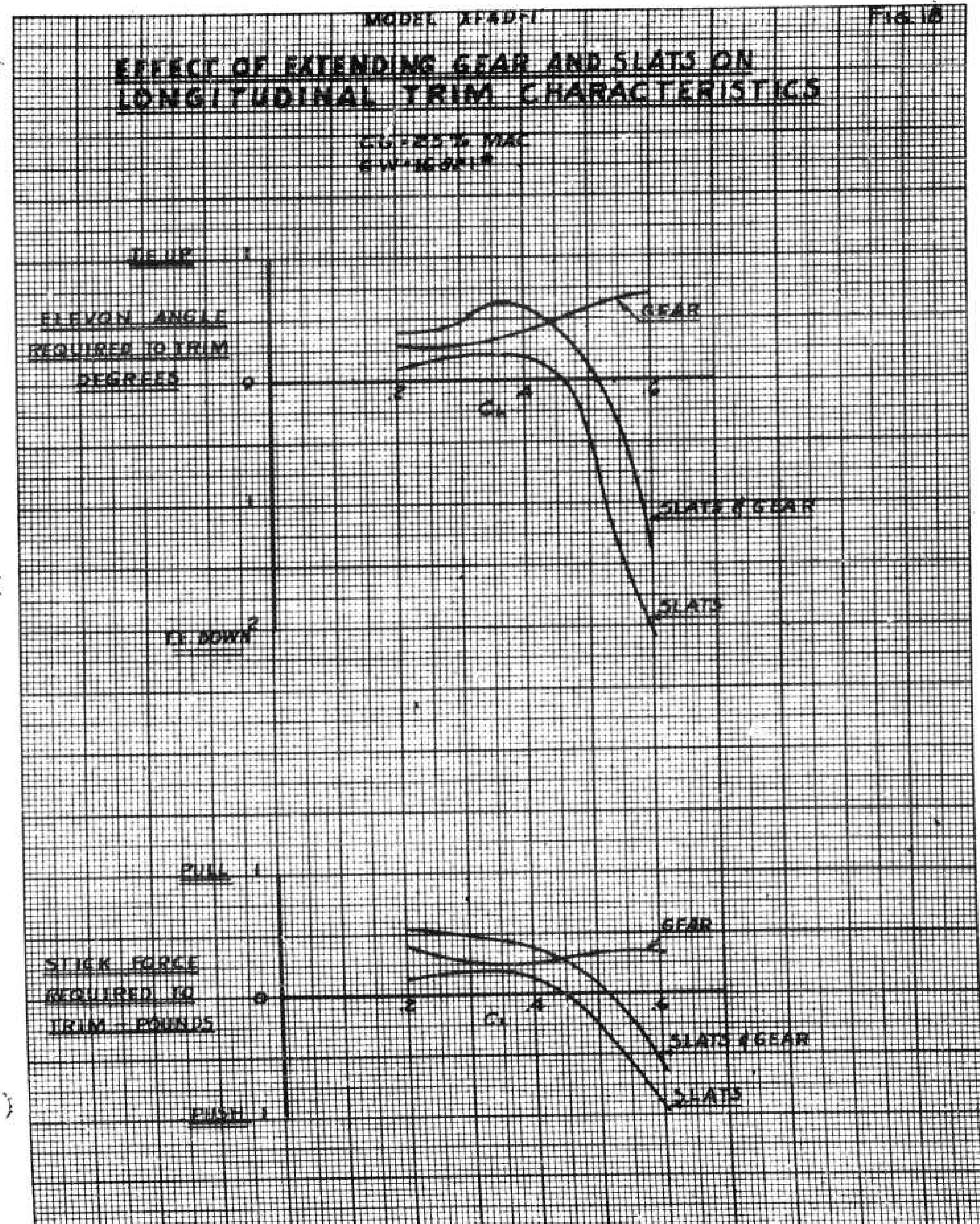
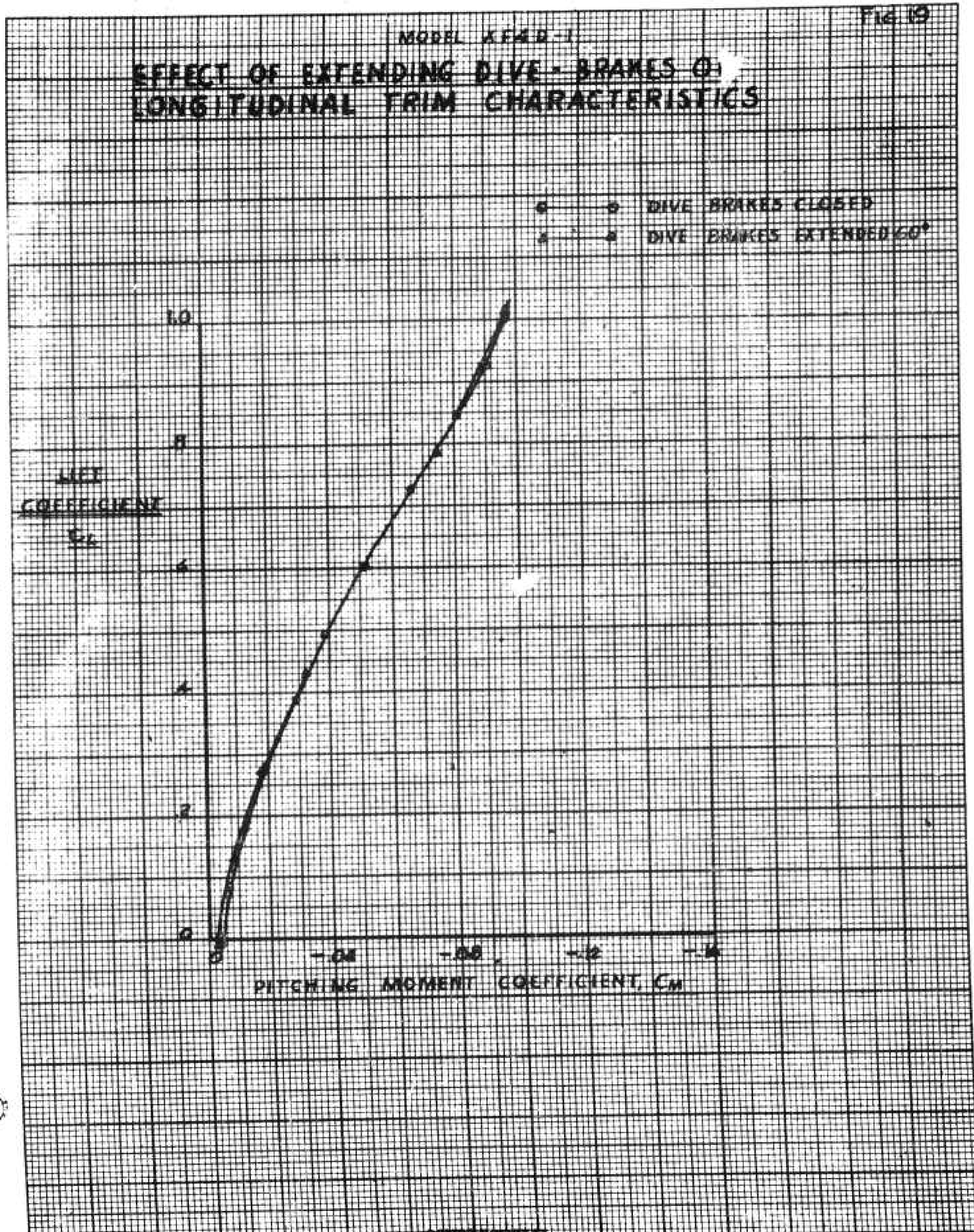


Fig 19


MODEL XF4D-1
EFFECT OF EXTENDING DIVE - BRAKES ON LONGITUDINAL TRIM CHARACTERISTICS
DIVE BRAKES CLOSED
DIVE BRAKES EXTENDED 60°
LIFT COEFFICIENT C_L
1.0
.8
.6
.4
.2
0
0
-.04
-.08
-.12
-.16
PITCHING MOMENT COEFFICIENT, C_M

moment acting on the elevon is reduced to a value of 64 ft-lbs., a spring in the interconnecting mechanism overcomes the pressure of the trapped hydraulic fluid and effectively pulls the pin holding the inboard and outboard elevons together. This action allows the inboard elevons to float free and the pilot is connected to the outboard surfaces only.

The simulated force feel device is disconnected at the time of hydraulic power failure. When this happens the stick will slip 3/8 of an inch, corresponding to the hydraulic servo valve travel, thus advising the pilot of the failure.

If the hinge moment acting on the elevons is below 64 ft-lbs. at the time of hydraulic failure, change-over will take place immediately and will manifest itself to the pilot by a force of less than 35 pounds to keep the airplane in trim.

8.1.3.2.1.2 Methods of Affecting Change-Over During High Elevon Hinge Moment Conditions

Since the change-over sequence is entirely automatic, it is expected that a minimum of pilot procedure will be required. However, the actions of the pilot immediately following hydraulic failure will influence the final force required to trim the airplane at a constant attitude.

Reduction of hinge moment may be accomplished in two ways; by moving the elevons towards trail position, or by slowing the airplane until the reduced dynamic pressure lowers the elevon hinge moments.

Moving the elevons toward trail position can be done without keeping the airplane in trim by simply moving the stick in the proper direction. When change-over occurs, an initial change in stick force of 35 pounds will be felt, but retrimming the airplane will either require increased stick forces or positioning the trimmer flap located inboard of the elevons. The airplane may be kept trimmed during change-over by slowly positioning the trimmer flap and at the same time moving the stick toward elevon trail position at the rate required to prevent a change in attitude. When change-over occurs using this procedure, the 35 pounds initial change in force will trim the airplane and large changes in airplane attitude are unlikely.

Under some conditions, it may be desirable to make the change-over by cutting power to reduce airspeed. When dynamic pressure becomes low enough to reduce the elevon hinge moments below 64 ft-lbs., change-over will take place.

8.1.3.2.2 Maximum Lift Characteristics

During emergency control operating conditions, primary pitch control is obtained from the outboard elevons, which are directly controlled by the pilot, plus the floating action of the inboard elevons. Additional control may be obtained by placing the trimmers in various up positions.

Obviously, maximum trimmed lift is obtained with the outboard elevons and trimmers fully deflected. This condition will only be approached in flight because the trimmers serve as a stick force trimmer when on manual control and its position will be limited to settings which give reasonable stick forces. Full deflection of the trimmers produces an unstable stick force versus speed gradient near the stall, as shown in Figure 20 , while intermediate trimmer settings result in stability in this flight region , (see Figure 21).

It follows that for a given center of gravity position, the minimum speed to which the airplane can be trimmed under emergency conditions will be dependent on the amount of stick free stability desired by the pilot.

8.1.3.2.3 Effect of Center of Gravity Position on Trimmer Position and Stick Forces Required for Landing

Curves of stick force, outboard and inboard elevon angles, and trimmer angle versus indicated airspeed are shown for two center of gravity positions in Figure 21 . The trimmer has been set so the stick forces at 1.4 V_{stall} are zero.

As the C.G. moves forward, more up trimmer is required to balance the increased negative pitching moment if the zero stick force speed is to remain constant. Stick free stability is increased during a forward center of gravity movement, but the minimum trim speed is slightly decreased.

Stick free stability appears to be satisfactory for the anticipated center of gravity range. Although the stick force versus speed gradient reverses near maximum lift for aft center of gravities, the force itself never approaches zero. Should the trimmer angle be increased over that required for trim at 1.4 V_{stall}, unstable stick forces will result for aft center of gravities.

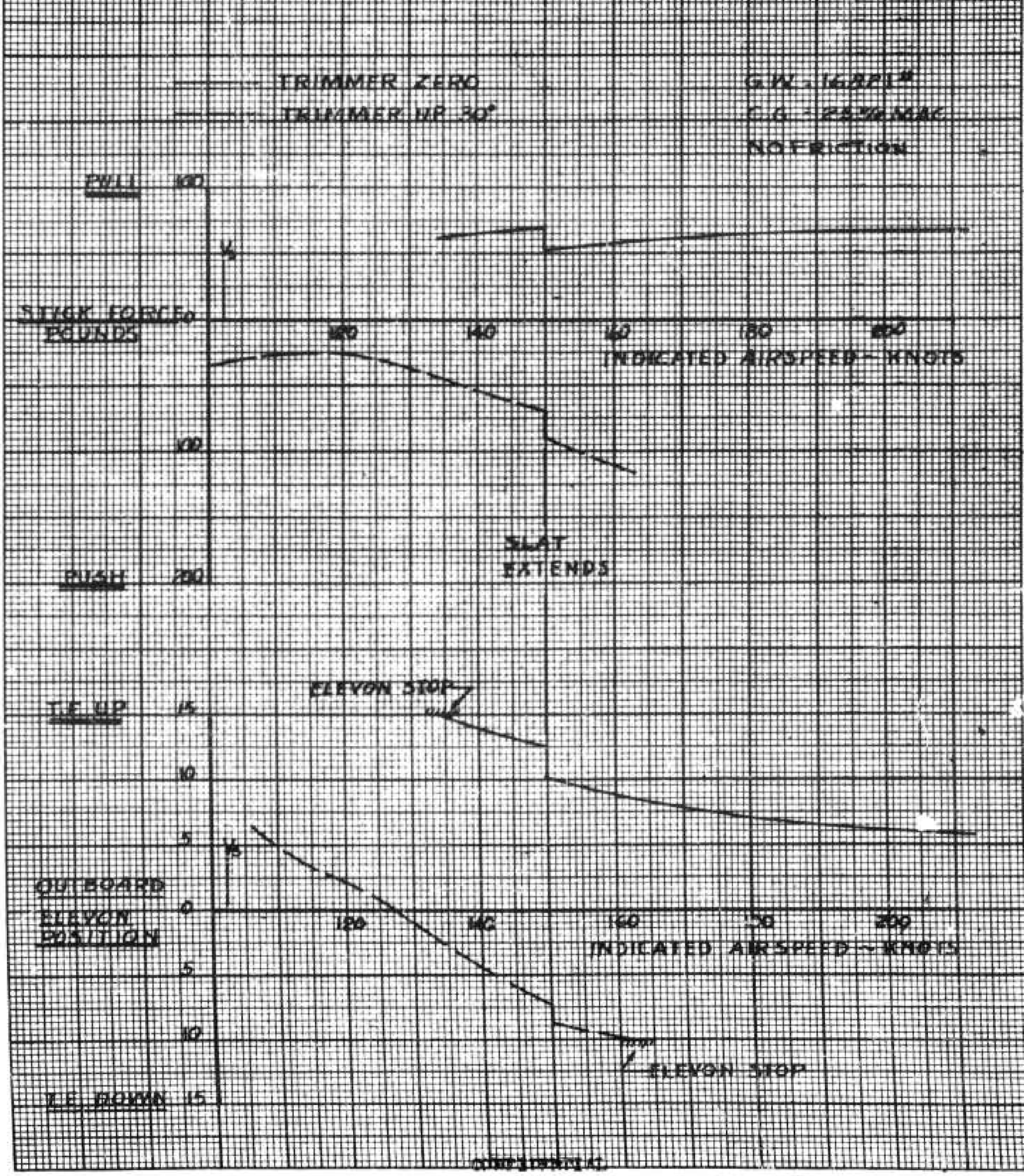
If the slat operating mechanism becomes inoperative, the floating angle of the outboard elevons is changed in such a manner as to reduce stick free stability below the speed at which the slats normally extend. Stability is further decreased as the center of gravity moves aft, and at the aft center of gravity of 25% MAC a condition of neutral stability appears to exist. These characteristics are shown in Figure 22 .

Trimmer position required for zero stick force over the low speed flight range is shown in Figure 23.

MODEL XF4D-1

FIG. 20

EFFECT OF TRIMMER ON STICK FORCES AND OUTBOARD ELEVON POSITION REQUIRED FOR TRIM ~ EMERGENCY CONTROL CONFIGURATION



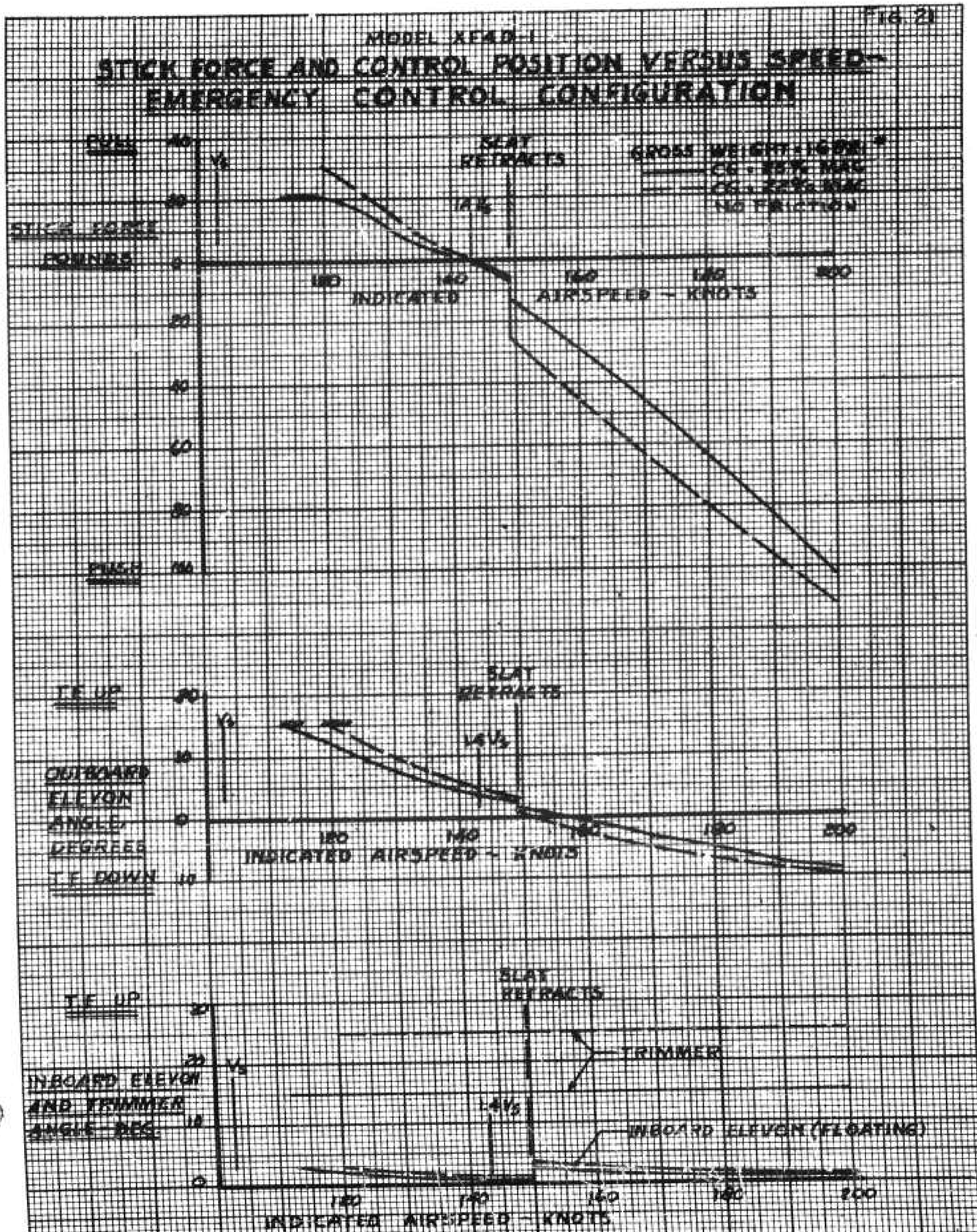


FIG. 21
MODEL XF4D-1
STICK FORCE AND CONTROL POSITION VERSUS SPEED—
EMERGENCY CONTROL CONFIGURATION
PULL
STICK FORCE POUNDS
PUSH
SLAT RETRACTS
GROSS WEIGHT
NO FRICTION
INDICATED AIRSPEED – KNOTS
T.E. UP
OUTBOARD ELEVON ANGLE, DEGREES
T.E. DOWN
INBOARD ELEVON AND TRIMMER ANGLE DEG.
TRIMMER
INBOARD ELEVON (FLOATING)
120
140
160
180
200

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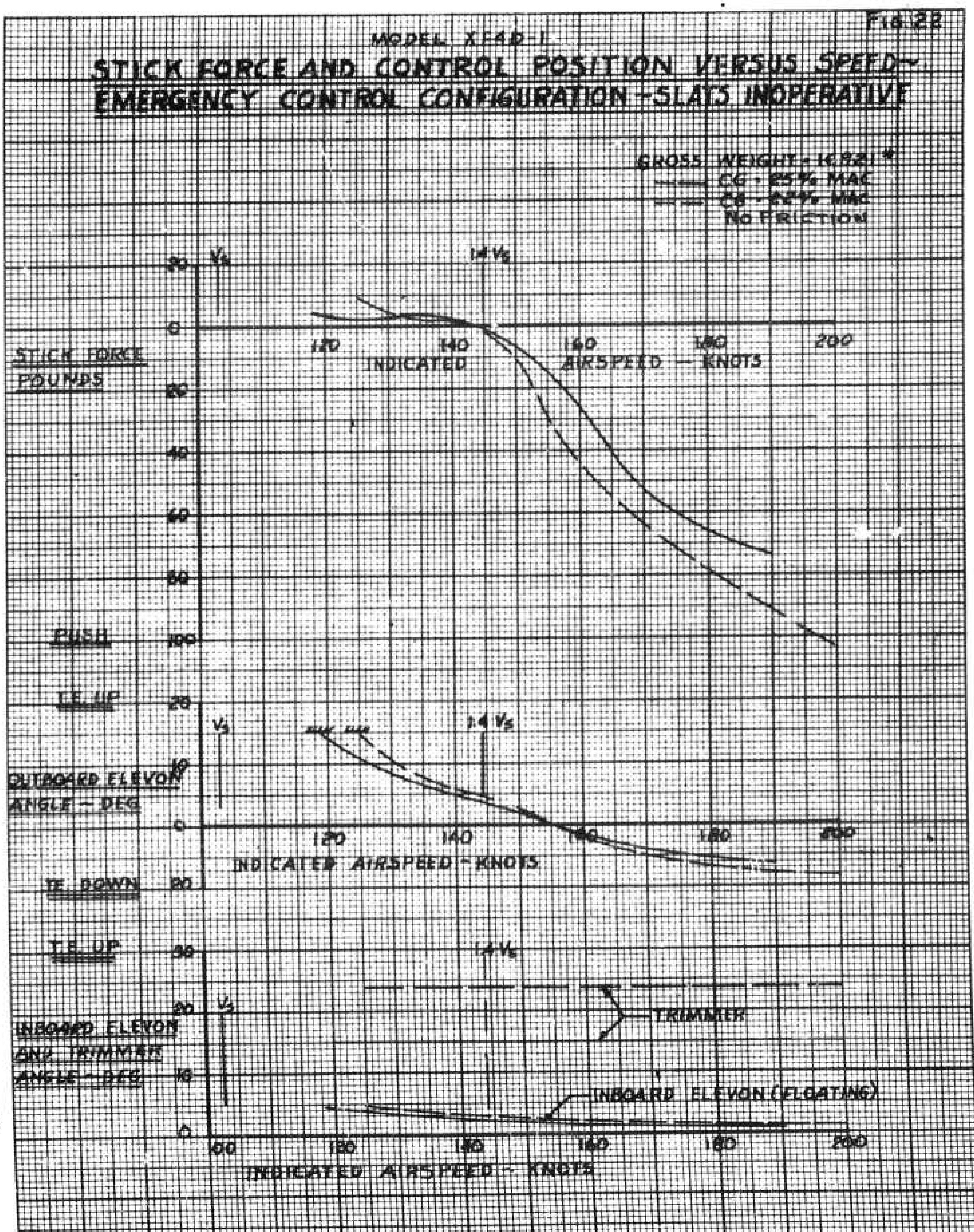

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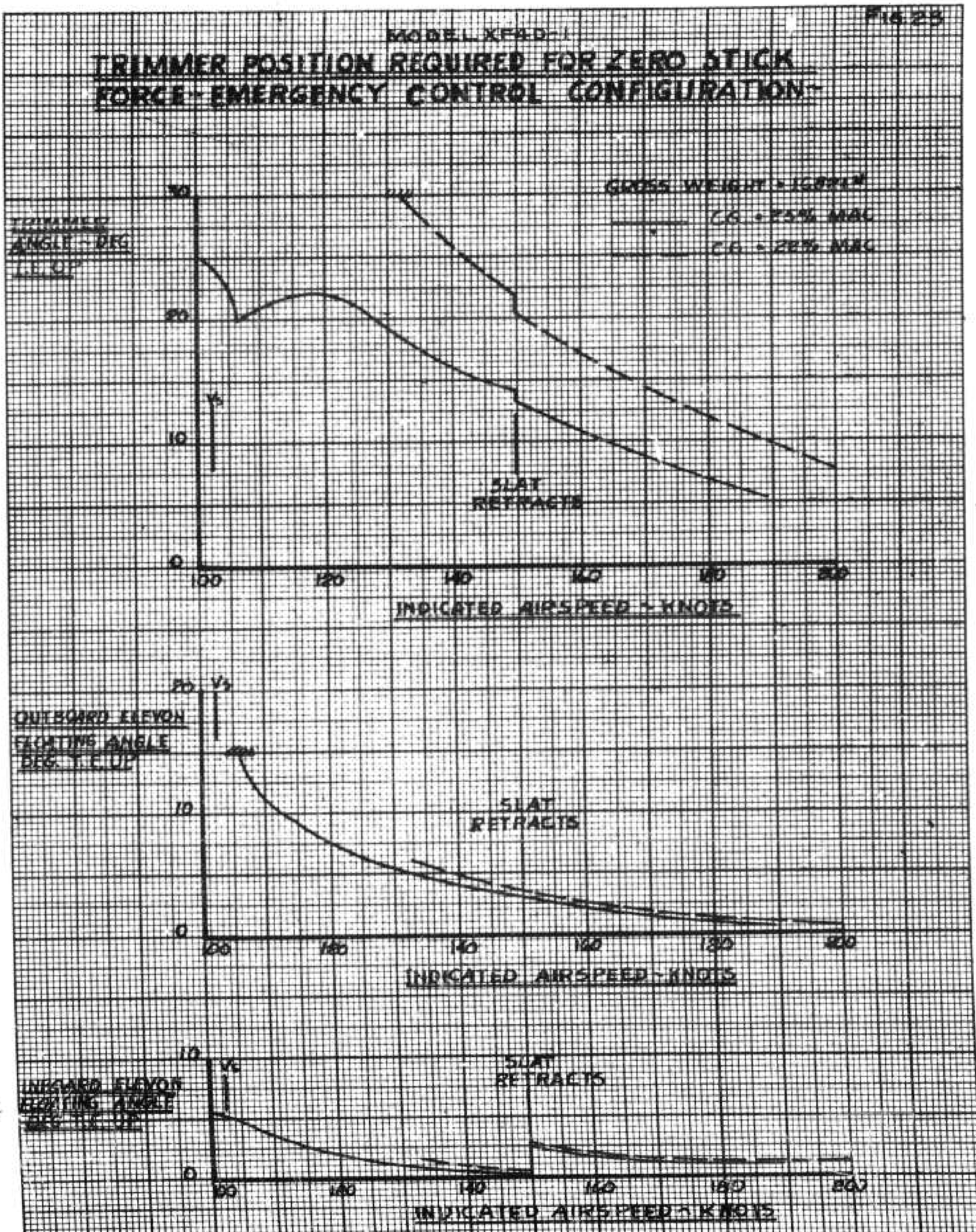
FIG 23
MODEL XF4D-1
TRIMMER POSITION REQUIRED FOR ZERO STICK FORCE - EMERGENCY CONTROL CONFIGURATION
CG = 25% MAC
CG = 28% MAC
TRIMMER ANGLE - DEG T.E. UP
Vs
SLAT RETRACTS
INDICATED AIRSPEED ~ KNOTS
OUTBOARD ELEVON FLOATING ANGLE DEG. T.E. UP
INBOARD ELEVON FLOATING ANGLE DEG. T.E. UP
0
10
20
30
100
120
140
160
180
200

8.1.3.2.4 Stick Force Characteristics During Accelerated Flight

Figures 24 and 25 present curves of outer elevon angle and stick force versus load factor for several indicated airspeeds. These values were calculated with the trimmer set to give zero stick force during level flight.

Examination of Figure 24 reveals the stick force per "g" gradient to be unstable at very low speeds with the C.G. at 25% MAC. As speed increases, the instability decreases until at 130 knots, pull forces are required to produce and hold a positive change in load factor. The instability noted is considered tolerable because it occurs over a very limited flight range and the magnitudes of the forces required are reasonable.

Moving the center of gravity forward decreases the range of flight over which instability occurs. Figure 25 shows the stick force per "g" gradient to be stable at all speeds down to the minimum.

Under emergency control operating conditions, maneuvering stability is unavoidably high. At speeds above 200 knots, all but routine maneuvering will require actuation of the trimmer to reduce stick forces to within the pilot's capabilities.

8.2 Directional Characteristics

8.2.1 Static Directional Stability

The static directional stability parameter, Cn_β, is plotted as a function of lift coefficient in Figure 26. Stability is positive at all speeds for normal operation, increasing from a value of .0011 at zero lift to .00193 at C_L = .85. If the airplane is flown with the slats retracted at lift coefficients above .60, stability decreases rapidly as lift coefficient increases and becomes neutral at C_L = .855.

Although Cn_β is somewhat lower than the estimated values given in Reference 3, no adverse results are anticipated. Damping of "dutch-roll" oscillations has always been marginal, and Reference 3 points out that an automatic yaw-damping system is to be installed in the airplane. As subsequent discussion will show, the net results are improved lateral-directional oscillatory characteristics and improved directional control.

Directional stability of the airplane is sufficient to restrict adverse yaw due to lateral elevon deflection to well within the limits specified by Reference 4. Characteristic time histories of airplane motion in rudder fixed rolls are presented in Figures 27, 28, 29 and 30 for several lift coefficients at sea level. From these time histories, maximum sideslip angles due to adverse yaw have been plotted and their relation to the maximum allowable is shown in Figure 31.

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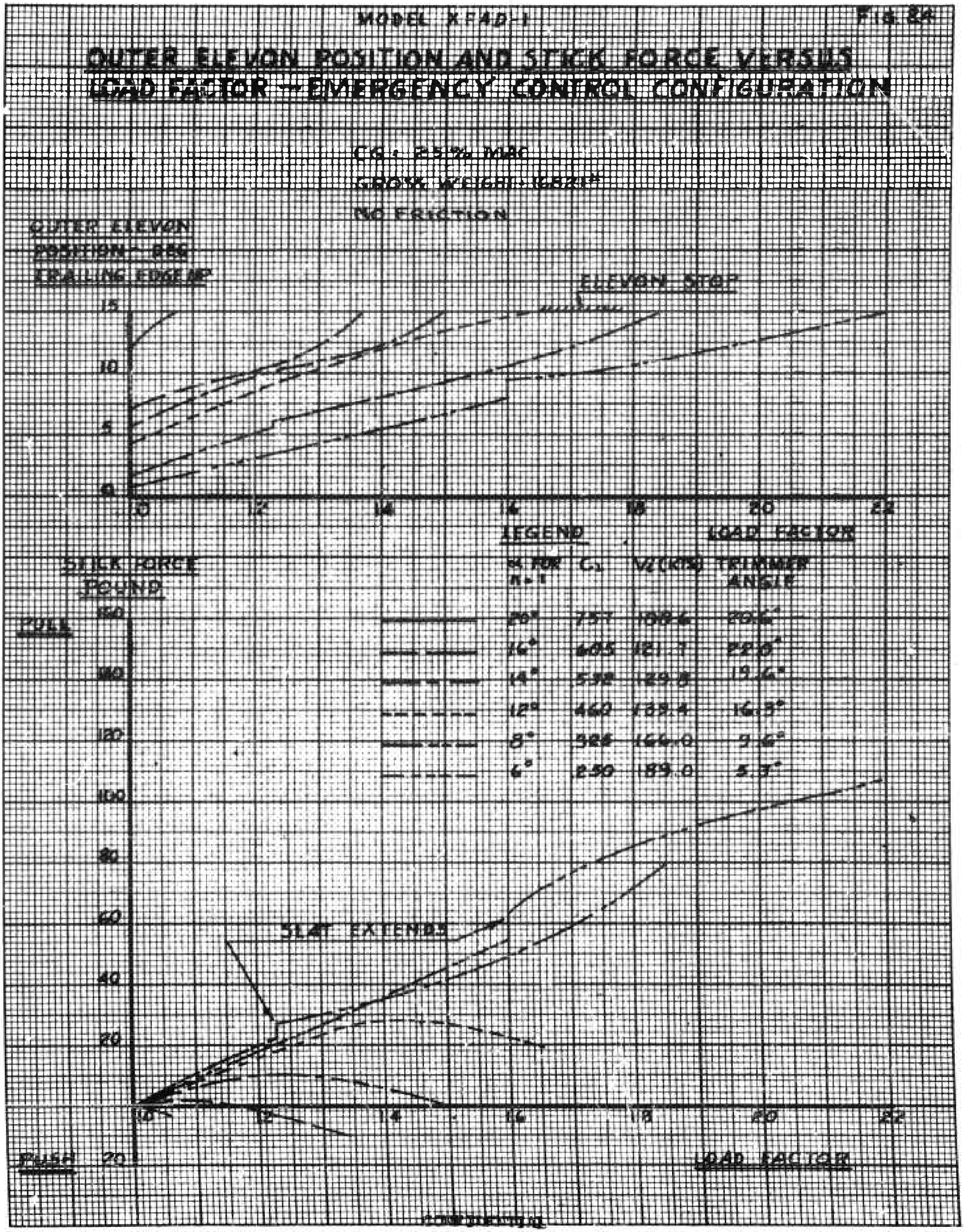

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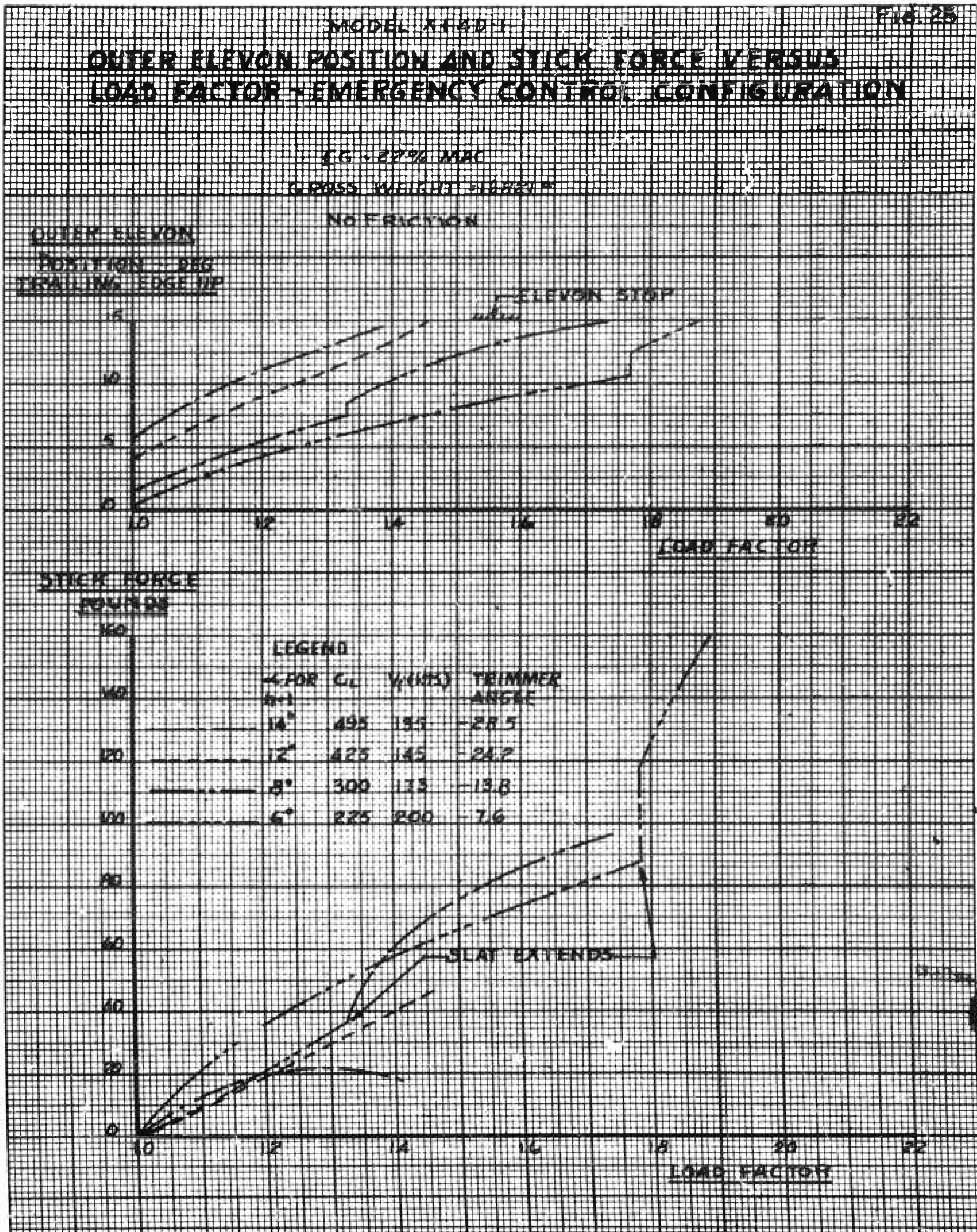


FIG. 25
MODEL XF4D-1
OUTER ELEVON POSITION AND STICK FORCE VERSUS LOAD FACTOR - EMERGENCY CONTROL CONFIGURATION
C.G. - 27% MAC
GROSS WEIGHT
NO FRICTION
OUTER ELEVON POSITION - DEG TRAILING EDGE UP
ELEVON STOP
15
10
5
0
10
12
14
16
18
20
22
LOAD FACTOR
STICK FORCE POUNDS
160
140
120
100
80
60
40
20
0
LEGEND
α FOR (n=1)
C_L
V_i (KTS)
TRIMMER ANGLE
14° 495 155 -28.5
12° 425 145 -24.2
8° 300 175 -13.8
6° 225 200 -7.6
SLAT EXTENDS
LOAD FACTOR

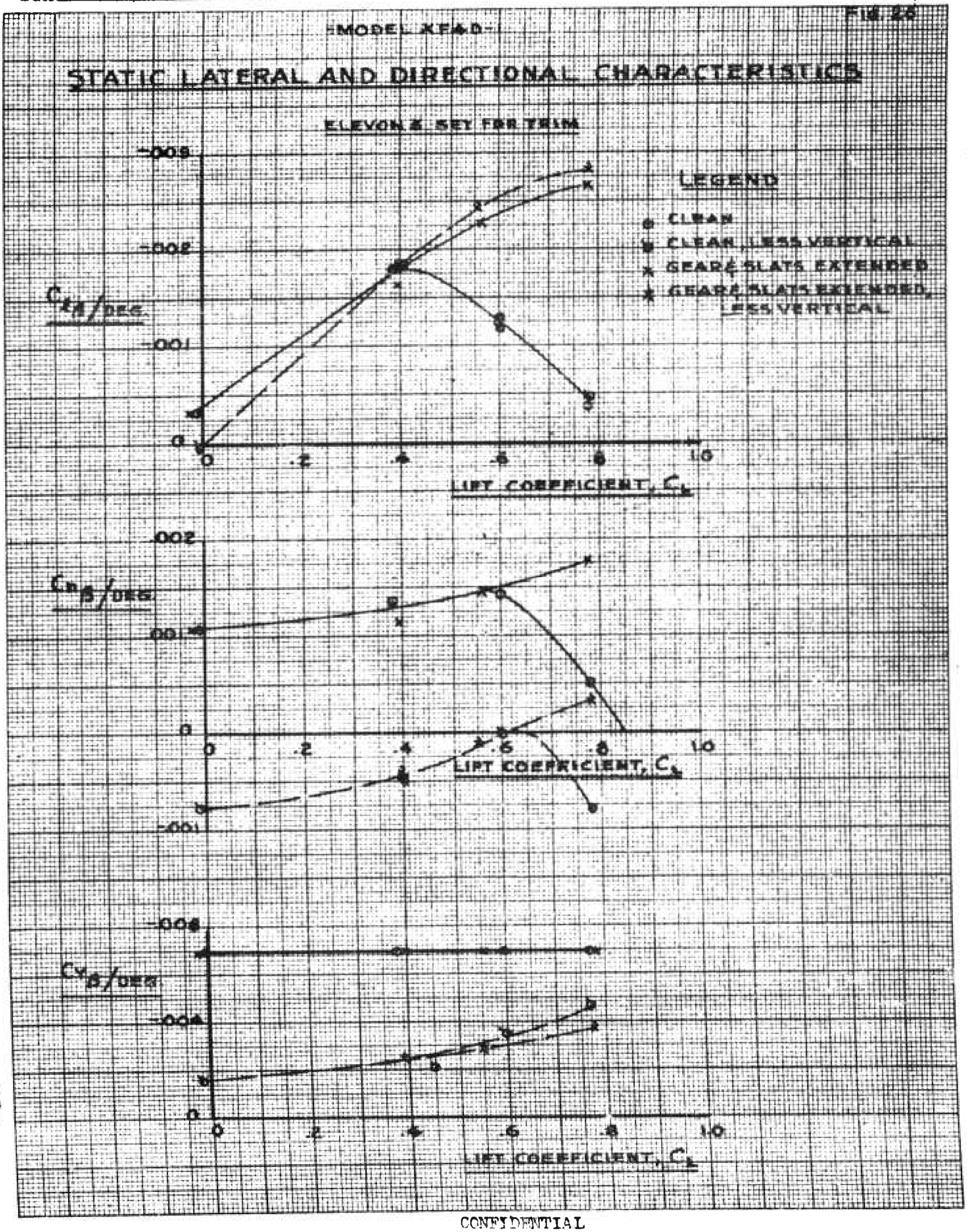


FIG. 26
MODEL XF4D-1
STATIC LATERAL AND DIRECTIONAL CHARACTERISTICS
ELEVONS SET FOR TRIM
LEGEND
CLEAN
CLEAN, LESS VERTICAL
GEAR & SLATS EXTENDED
GEAR & SLATS EXTENDED, LESS VERTICAL
C_{l_β}/DEG.
-.003
-.002
-.001
0
0
.2
.4
.6
.8
1.0
LIFT COEFFICIENT, C_L
C_{n_β}/DEG.
.002
.001
0
-.001
LIFT COEFFICIENT, C_L
C_{Y_β}/DEG.
-.008
-.004
0
LIFT COEFFICIENT, C_L

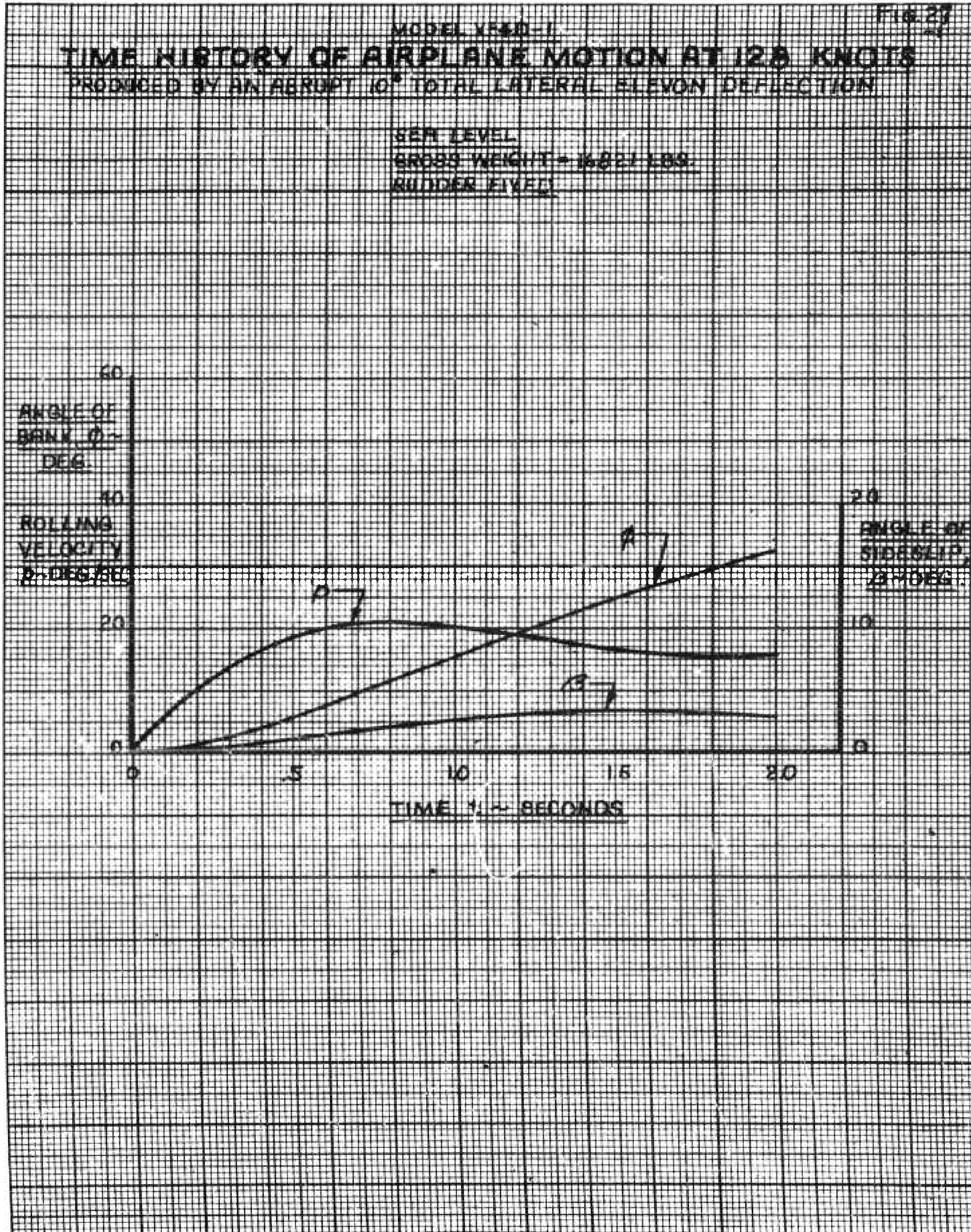
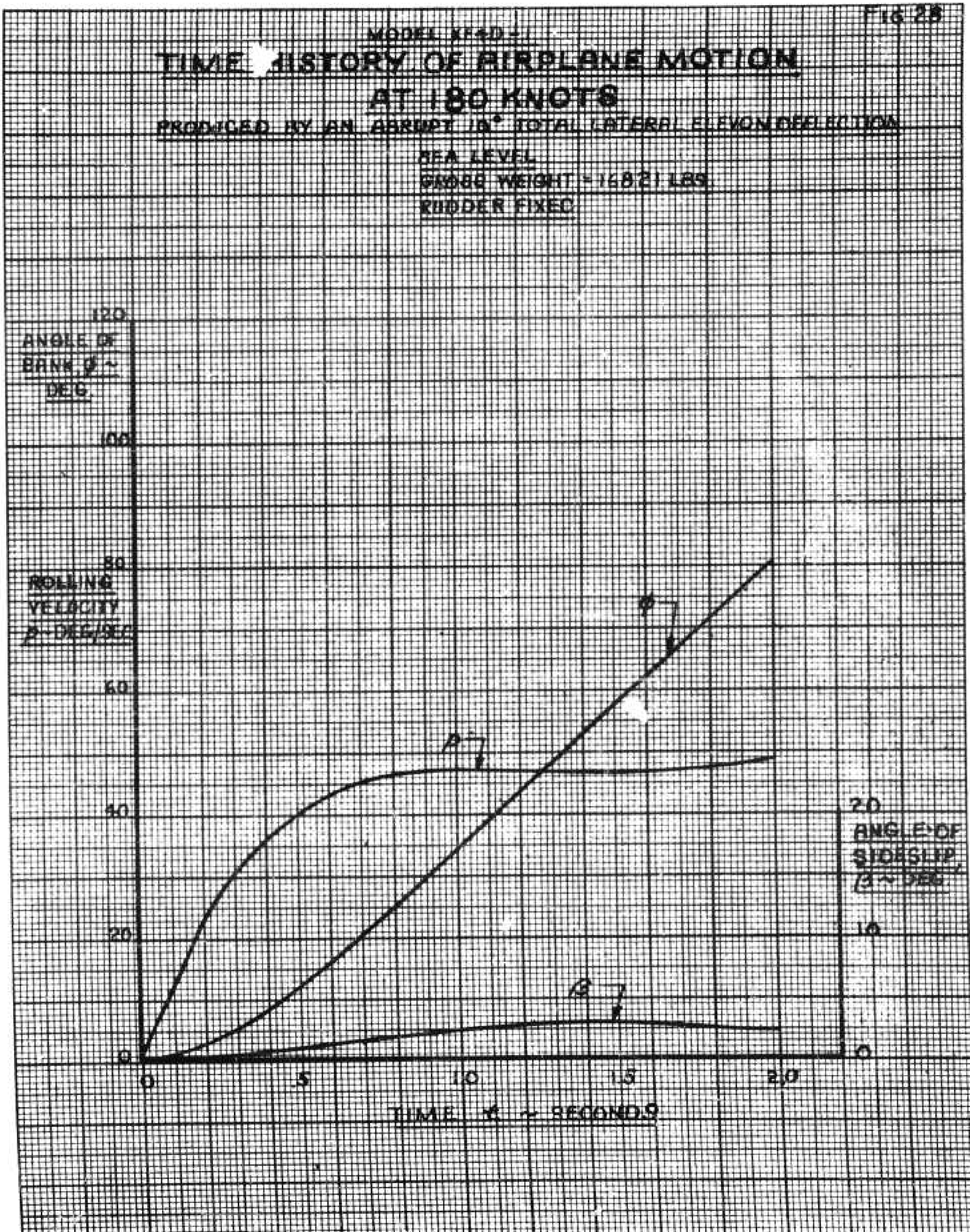
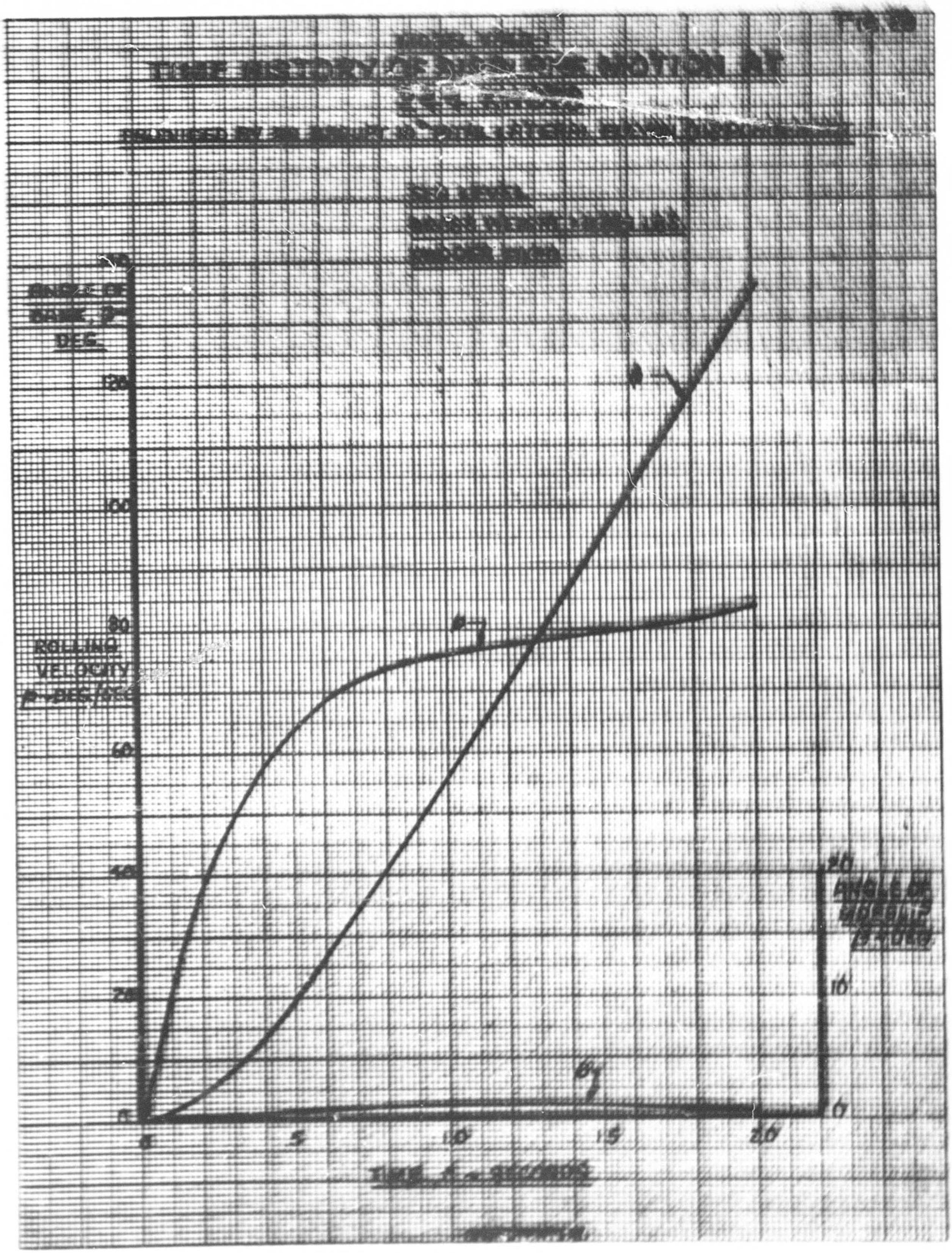
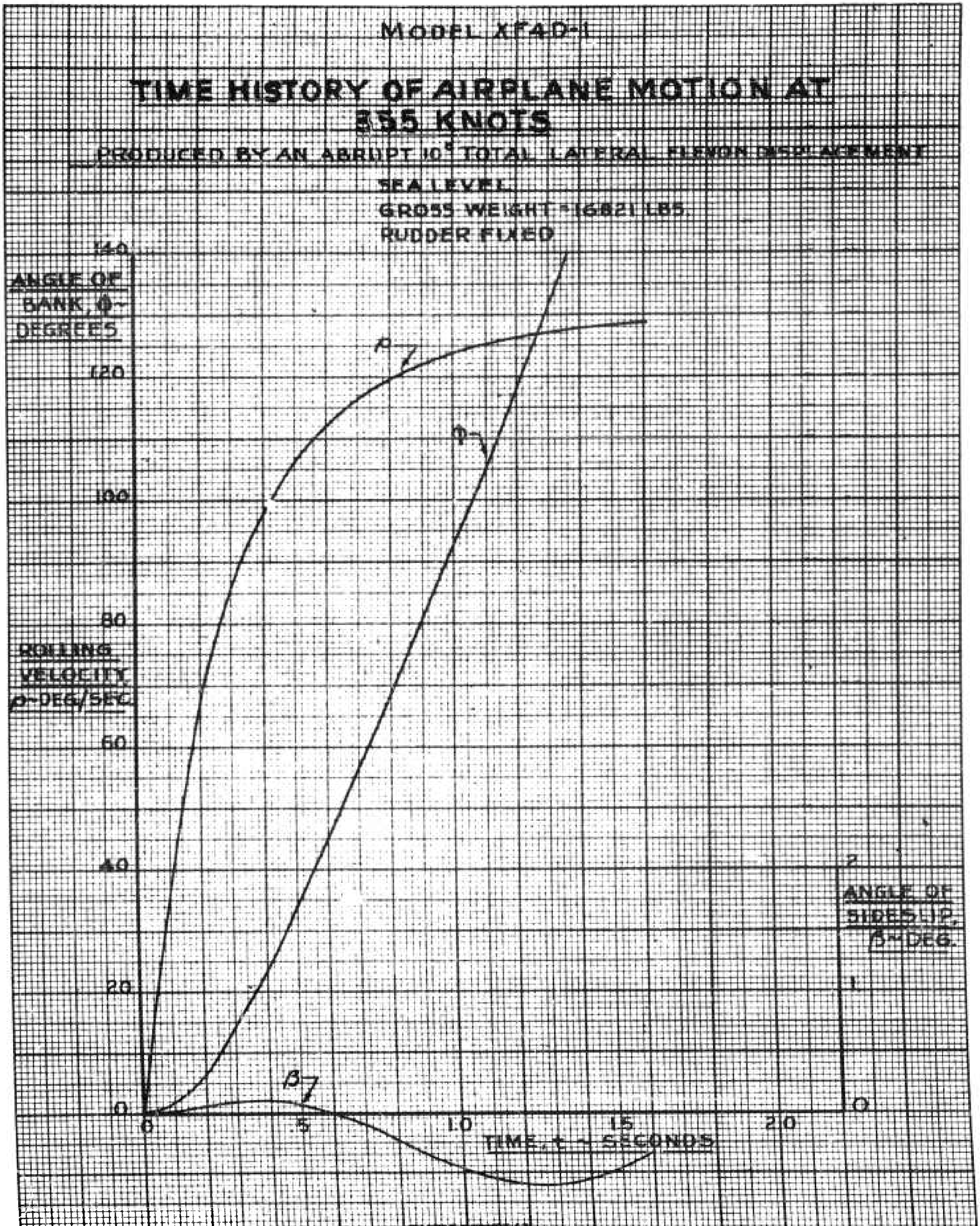


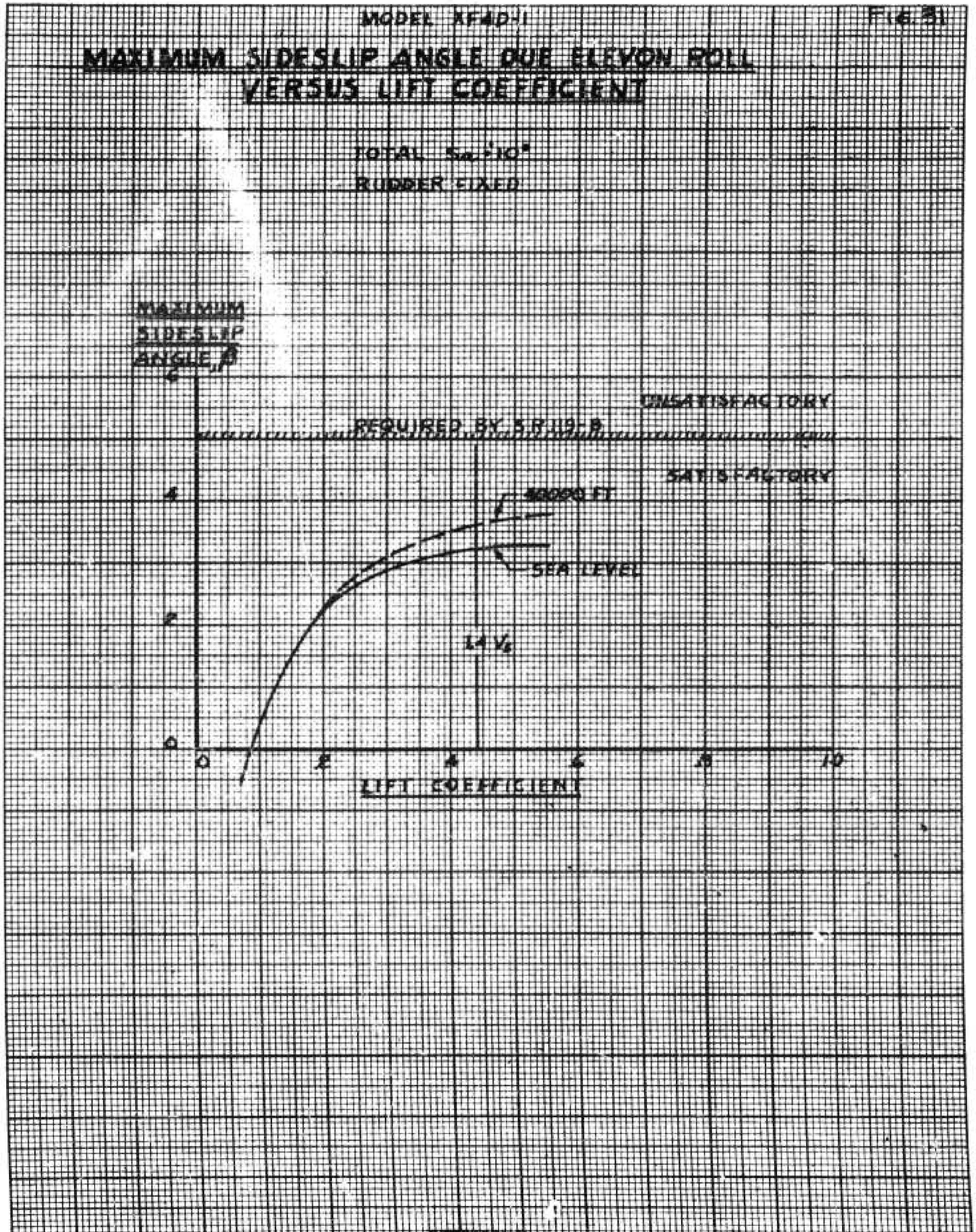
FIG. 27
MODEL XF4D-1
TIME HISTORY OF AIRPLANE MOTION AT 128 KNOTS
PRODUCED BY AN ABRUPT 10° TOTAL LATERAL ELEVON DEFLECTION
SEA LEVEL
GROSS WEIGHT = 16821 LBS.
RUDDER FIXED
ANGLE OF BANK, Ø ~ DEG.
ROLLING VELOCITY p ~ DEG/SEC
ANGLE OF SIDESLIP, β ~ DEG.
60
40
20
0
2.0
1.0
0
Ø
p
β
0
.5
1.0
1.5
2.0
TIME, t ~ SECONDS

FIG 28


MODEL XF4D-1
TIME HISTORY OF AIRPLANE MOTION
AT 180 KNOTS
PRODUCED BY AN ABRUPT 10° TOTAL LATERAL ELEVON DEFLECTION
SEA LEVEL
GROSS WEIGHT - 16821 LBS
RUDDER FIXED
120
ANGLE OF BANK Φ ~ DEG
100
80
ROLLING VELOCITY p ~ DEG/SEC
60
40
20
0
Φ
p
β
2.0
ANGLE OF SIDESLIP β ~ DEG
1.0
0
0
.5
1.0
1.5
2.0
TIME t ~ SECONDS


HISTORY
MOTION AT
ANGLE OF BANK, ϕ DEG.
ROLLING VELOCITY p - DEG/SEC
ANGLE OF SIDESLIP
ϕ
p
β
0
20
40
60
80
100
120
10
20
0
.5
1.0
1.5
2.0


MODEL XF4D-1
TIME HISTORY OF AIRPLANE MOTION AT 355 KNOTS
PRODUCED BY AN ABRUPT 10° TOTAL LATERAL ELEVON DISPLACEMENT
SEA LEVEL
GROSS WEIGHT = 16821 LBS.
RUDDER FIXED
ANGLE OF BANK, ϕ~DEGREES
ROLLING VELOCITY, p~DEG/SEC
ANGLE OF SIDESLIP, β~DEG.
TIME, t ~ SECONDS
p
ϕ
β
140
120
100
80
60
40
20
0
0
.5
1.0
1.5
2.0
2
1
0


MODEL XF4D-1
FIG. 31
MAXIMUM SIDESLIP ANGLE DUE ELEVON ROLL
VERSUS LIFT COEFFICIENT
TOTAL δa = 10°
RUDDER FIXED
MAXIMUM SIDESLIP ANGLE, β
UNSATISFACTORY
REQUIRED BY SR 119-B
SATISFACTORY
40000 FT
SEA LEVEL
1.4 Vs
0
2
4
6
.2
.4
.6
.8
1.0
LIFT COEFFICIENT

Rudder floating tendency is estimated to be negligible, thus insuring rudder-free characteristics comparable with rudder fixed estimates. Trim for level flight at zero side slip will be satisfactory since there are no asymmetric power effects.

8.2.2 Description of Dutch Roll Damping System

References 5 and 6 indicated damping of the lateral-directional oscillation was marginal. Further analysis of the problem, Reference 3 showed that it is impossible to materially improve the damping characteristics by changing the airplane configuration and that addition of artificial damping appeared to be the logical solution.

A yaw damper consisting of a rate-gyro sensitive to rate of yaw and a servo-system controlling rudder motion is to be installed in the XF4D-1 to improve lateral-directional damping. The basic relationship between the rate-gyro and the servo-mechanism which receives its signal is that one degree rate of yaw will excite one degree of rudder to oppose the yaw.

The characteristics of the artificial damping system are non-linear as a result of power limitations of the servo system, static friction and non-linearities inherent in the servo system. These considerations will influence effectiveness of the yaw damper, and their effects are now in the process of determination.

To prevent the system from damping intentional turns, a force link sensitive to rudder pedal force imparts a signal to the servo-mechanism that cancels the signal output from the rate-gyro during manuevers involving a change of azimuth. In this respect the XF4D-1 will differ from conventional airplanes in that a rudder pedal force proportional to rate of yaw must be applied to maintain steady turns.

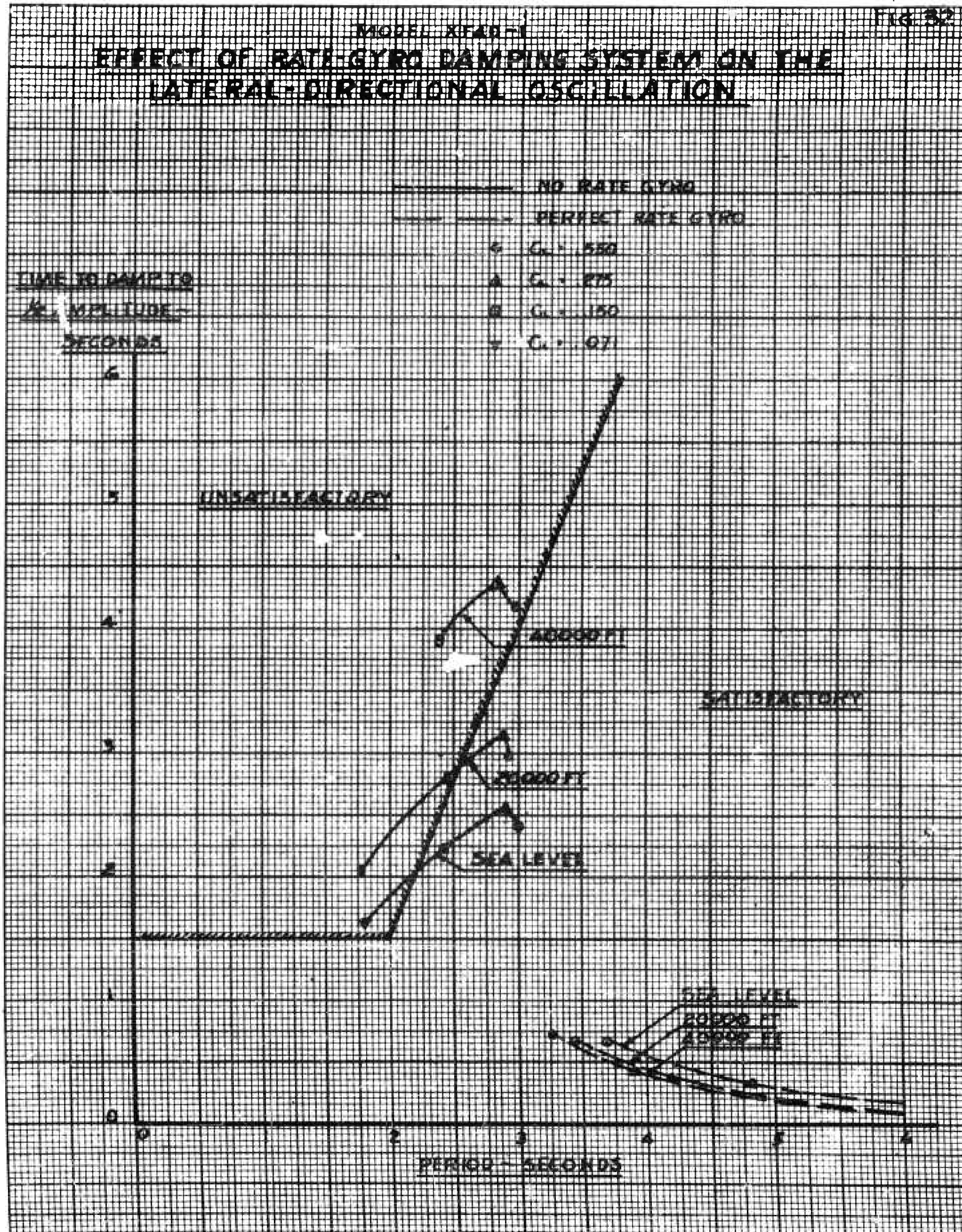
Characteristics of the actual system to be installed in the airplane will be presented in Reference 7, to be published soon.

8.2.3 Dynamic Lateral-Directional Characteristics

Damping characteristics of Model XF4D-1 are shown in Figure 32 for several lift coefficients at various altitudes. A summary of the mass and aerodynamic parameters used in the calculations is given in Table 4.

The solid lines of Figure 32 represent damping characteristics of the airplane with no artificial damping. Calculations of these points were made using the latest wind tunnel data of Reference 1. The relation between period of the oscillation and time to damp to one-half amplitude is seen to be marginal at sea level and tends toward unsatisfactory as altitude increases.

FIG 32


MODEL XF4D-1
EFFECT OF RATE-GYRO DAMPING SYSTEM ON THE LATERAL-DIRECTIONAL OSCILLATION
NO RATE GYRO
PERFECT RATE GYRO
TIME TO DAMP TO ½ AMPLITUDE - SECONDS
UNSATISFACTORY
40000 FT
SATISFACTORY
20000 FT
SEA LEVEL
SEA LEVEL
20000 FT
40000 FT
0
1
2
3
4
5
6
0
2
3
4
5
6
PERIOD - SECONDS

FORM 30-250 10-1-47

DOUGLAS AIRCRAFT COMPANY, INC. EL SEGUNDO PLANT EL SEGUNDO, CALIFORNIA

TABLE 4

SUMMARY OF PARAMETERS USED IN DYNAMIC LATERAL-DIRECTIONAL STABILITY CALCULATION - NO ARTIFICIAL DAMPING

Altitude	Sea Level			
C_L	.550	.275	.150	.071
V, FPS	223.3	315.8	427.5	621.5
$b/_{2V}$	.0751	.05303	.03918	.02695
$2b\mu/_V$	3.529	2.495	1.843	1.268
$C_{\ell\dot{\phi}}$	-.01470	-.01390	-.00768	-.00528
$C_{n\dot{\phi}}$	-.00119	-.00035	.000110	.000455
$C_{Y\dot{\phi}}$	.02254	.00559	.00072	-.00103
$C_{\ell\dot{\psi}}$	.01016	.00453	.00245	.00130
$C_{n\dot{\psi}}$	-.00620	-.00473	-.00350	-.00242
$C_{Y\dot{\psi}}$	.00805	.00994	.00801	.00568
$C_{\ell\beta}$	-.1300	-.0791	-.0527	-.0356
$C_{n\beta}$	.0831	.0693	.0653	.0630
$C_{Y\beta}$	-.338	-.338	-.338	-.338
Ix	.01183	.00526	.00279	.00131
Iz	.03792	.01962	.01078	.00512
Ixz	-.00695	-.00174	-.00051	-.00010

PERFECT RATE GYRO

ALL PARAMETERS SAME AS ABOVE EXCEPT THOSE AFFECTED BY RUDDER DEFLECTION, $C_{n\dot{\psi}}$, $C_{\ell\dot{\psi}}$, $C_{Y\dot{\psi}}$.

C_L	.550	.275	.150	.071
$C_{\ell\dot{\psi}}$	.00701	.00797	.00892	.00966
$C_{n\dot{\psi}}$	-.05600	-.05633	-.05790	-.05772
$C_{Y\dot{\psi}}$	.09405	.10324	.10801	.10988

TABLE 4 (Cont'd)

NO ARTIFICIAL DAMPING				
Altitude		20,000 Ft.		
C_L	.550	.275	.150	.071
V, FPS	294.3	416.3	563.6	819.3
$b/2V$	.05691	.04023	.02971	.02044
$2b\mu/V$	5.027	3.554	2.625	1.806
$C_{\ell_{\dot\phi}}$	-.01115	-.00789	-.00582	-.00401
$C_{n_{\dot\phi}}$	-.000905	-.000266	.000083	.000345
$C_{Y_{\dot\phi}}$	.01710	.00424	.00055	-.00078
$C_{\ell_{\dot\psi}}$	.00771	.00344	.00186	.00099
$C_{n_{\dot\psi}}$	-.00471	-.00359	-.00266	-.00184
$C_{Y_{\dot\psi}}$	.00611	.00754	.00607	.00431
C_{ℓ_β}	-.1300	-.0791	-.0527	-.0356
C_{n_β}	.0831	.0693	.0653	.0630
C_{Y_β}	-.338	-.338	-.338	-.338
I_x	.01183	.00526	.00279	.00131
I_z	.03792	.01962	.01078	.00512
I_{x_z}	-.00695	-.00174	-.00051	-.00010

PERFECT RATE GYRO

ALL PARAMETERS SAME AS ABOVE EXCEPT THOSE AFFECTED BY RUDDER DEFLECTION, $C_{n_{\dot\psi_r}}$, $C_{\ell_{\dot\psi_r}}$, $C_{Y_{\dot\psi_r}}$.

C_L	.550	.275	.150	.071
$C_{\ell_{\dot\psi_r}}$	.00456	.00688	.00833	.00935
$C_{n_{\dot\psi_r}}$	-.05451	-.05519	-.05706	-.05714
$C_{Y_{\dot\psi_r}}$	.09211	.10084	.10607	.10851

FORM 30-250 10-1-47

TABLE 4 (Cont'd)

NO ARTIFICIAL DAMPING			
Altitude	40,000 Ft.		
C_L	.550	.275	.150
V, FPS	434.4	614.5	831.8
b/2V	.03855	.02725	.02013
$2b\mu/V$	7.409	5.238	3.870
$C_{\ell_{\dot\phi}}$	-.00756	-.00534	-.00700
$C_{n_{\dot\phi}}$	-.000613	-.000180	.000056
$C_{Y_{\dot\phi}}$	.01158	.00287	.00037
$C_{\ell_{\dot\psi}}$	.00522	.00233	.00126
$C_{n_{\dot\psi}}$	-.00319	-.00243	-.00180
$C_{Y_{\dot\psi}}$	.00414	.00511	.00411
C_{ℓ_β}	-.1300	-.0791	-.0527
C_{n_β}	.0831	.0693	.0653
C_{Y_β}	-.338	-.338	-.338
I_x	.01183	.00526	.00279
I_z	.03792	.01962	.01078
I_{xz}	-.00695	-.00174	-.00051

PERFECT RATE GYRO

ALL PARAMETERS SAME AS ABOVE EXCEPT THOSE AFFECTED BY RUDDER DEFLECTION, $C_{n_{\dot\psi}}$, $C_{\ell_{\dot\psi}}$, $C_{Y_{\dot\psi}}$.

C_L	.550	.275	.150
$C_{\ell_{\dot\psi}}$	.00207	.00577	.00773
$C_{n_{\dot\psi}}$	-.05299	-.05403	-.05620
$C_{Y_{\dot\psi}}$	.09014	.09841	.10411

Estimates of the effect of introducing artificial damping have been made assuming a perfect rate-gyro system. Results of these calculations are represented by the broken lines of Figure 32 . Negligible oscillation appears to be present. It is interesting to note that for the case of the airplane with no artificial damping, damping characteristics became worse as speed increases. For the case of the airplane with artificial damping the reverse is true. The reason for this reversed trend is obvious when the damping in yaw parameters, $C_{n_{\dot\psi}}$, are observed for the two cases in Table 4 . Induced damping from the rudder is so large that at high speeds the oscillation really never gets started.

The yaw damping system that is to be installed in the XF4D-1 will produce results that lie between the two cases presented here. It is believed the final configuration will produce entirely satisfactory dynamic lateral-directional oscillatory characteristics.

8.2.4 Directional Control

8.2.4.1 Side Slip Characteristics and Rudder Pedal Forces-Yaw Damper Inoperative

Rudder effectiveness parameters Cn_{δ_r}, Cl_{δ_r} and Cy_{δ_r} are plotted against lift coefficient in Figure 33 . The rate of change of yawing moment coefficient with rudder deflection is linear over the complete flight range of the airplane and indicates that excellent directional control may be maintained under all conditions.

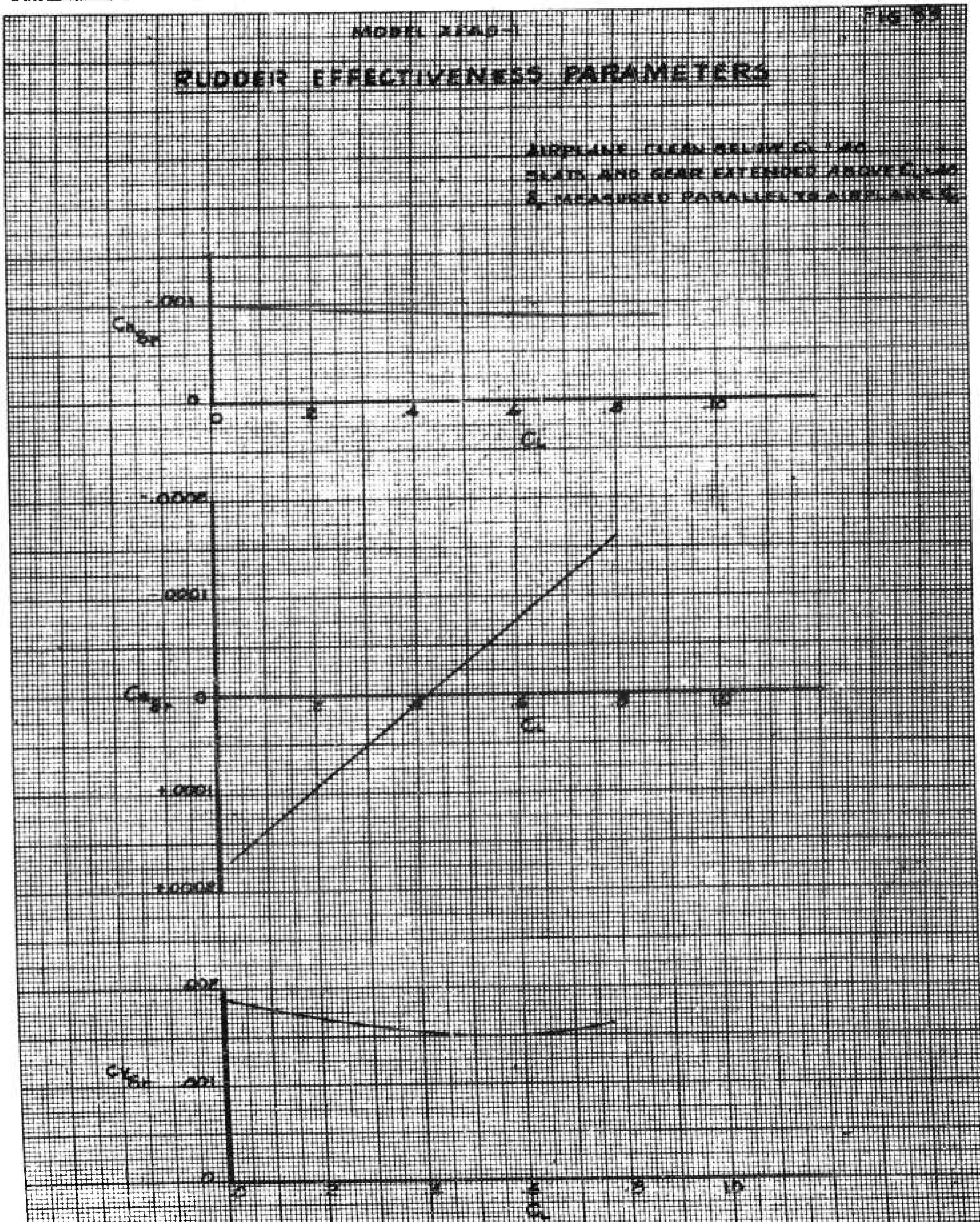
Figures 34,35,36 and 37 present curves of steady side slip angle, β, versus angle of bank, right aileron angle, and rudder deflection for angles of attack of 0°, 10°, 15°, and 20° respectively. These curves were cross plotted to obtain the maximum steady side slip angle obtainable and associated control positions for various angles of attack, as shown in Figure 38 .

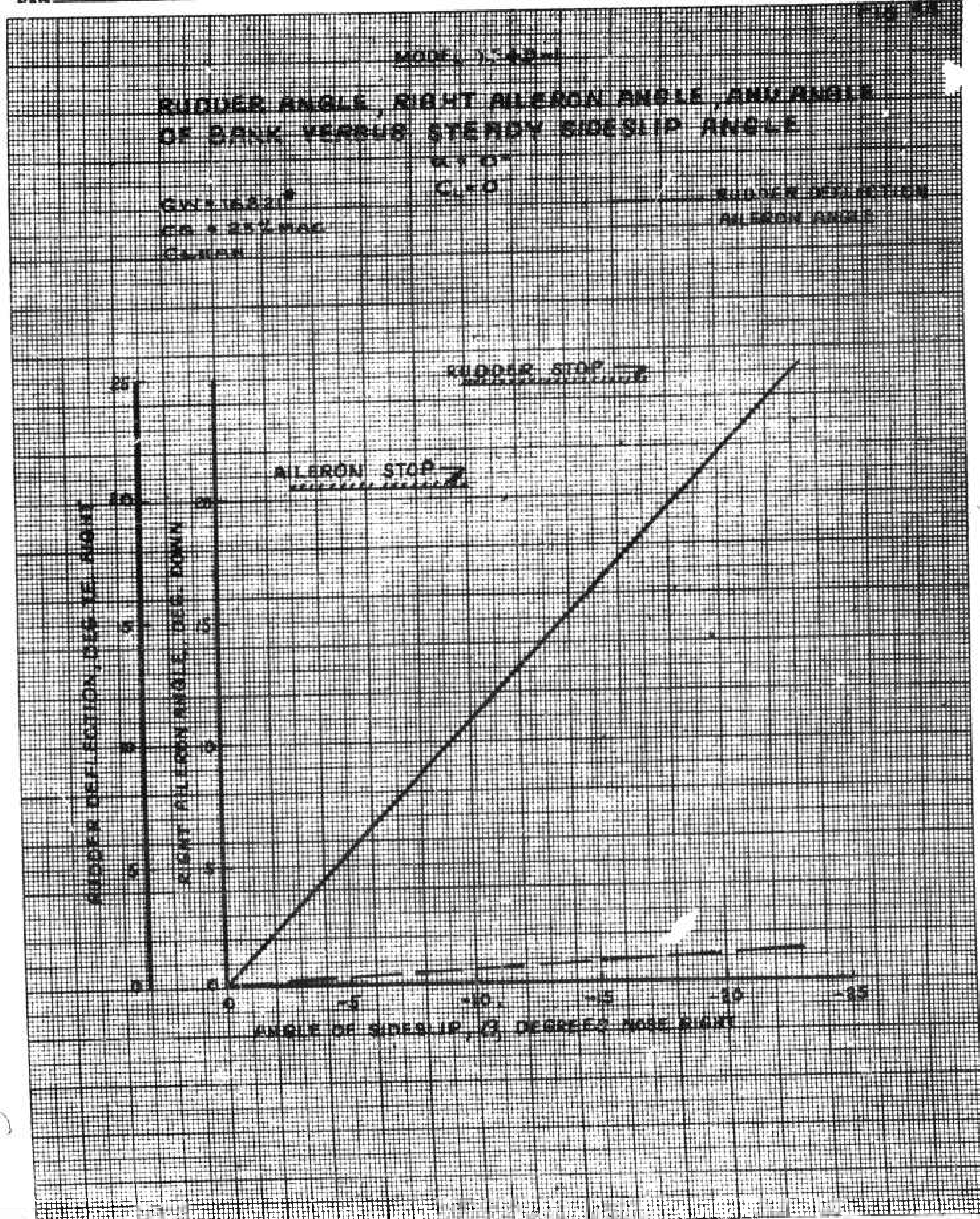
The maximum side slip angle at 1.1 V_{stall} is 12.8°. The rudder pedal force required for the case of the airplane with no yaw damper is 57 pounds. These values are well within the requirements of Reference 4 .

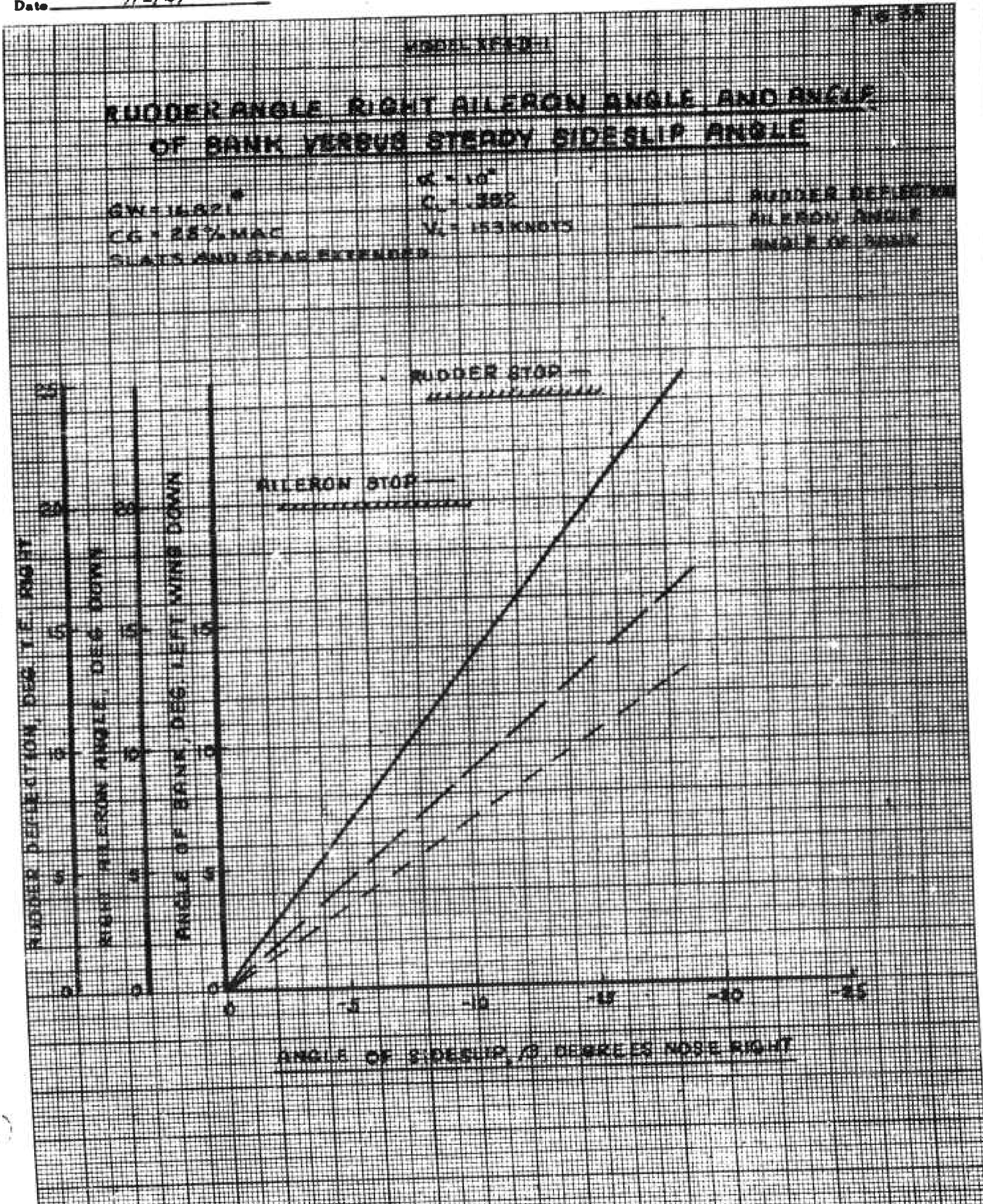
Cross wind take-off characteristics are shown in Figure 39 . Available side slip angles and associated rudder pedal forces meet the requirements of Reference 4 .

8.2.4.2 Side Slip Characteristics and Rudder Pedal Forces-Yaw Damper Operating

The yaw damper and rudder pedal force link are being designed so that their addition to the control system will in no way restrict directional control. Hence the same angles of sideslip presented in Section 8.2.4.1 will be obtainable with the yaw damper installed.


RUDDER EFFECTIVENESS PARAMETERS
CL
CL
CL


RUDDER ANGLE, RIGHT AILERON ANGLE, AND ANGLE OF BANK VERSUS STEADY SIDESLIP ANGLE
GW = 16321#
CG = 25% MAC
CLEAN
C_L = 0
RUDDER DEFLECTION
AILERON ANGLE
RUDDER STOP
AILERON STOP
RUDDER DEFLECTION, DEG. TE. RIGHT
RIGHT AILERON ANGLE, DEG. DOWN
0
5
10
15
20
25
0
-5
-10
-15
-20
-25
ANGLE OF SIDESLIP, β, DEGREES NOSE RIGHT



MODEL XF4D-1
RUDDER ANGLE, RIGHT AILERON ANGLE, AND ANGLE OF BANK VERSUS STEADY SIDESLIP ANGLE
GW = 16821#
CG = 25% MAC
SLATS AND GEAR EXTENDED
C_L = .382
RUDDER DEFLECTION
AILERON ANGLE
ANGLE OF BANK
RUDDER STOP
AILERON STOP
RUDDER DEFLECTION, DEG. T.E. RIGHT
RIGHT AILERON ANGLE, DEG. DOWN
ANGLE OF BANK, DEG. LEFT WING DOWN
ANGLE OF SIDESLIP, β, DEGREES NOSE RIGHT
0
-5
-10
-15
-20
-25
5
10
15
20
25

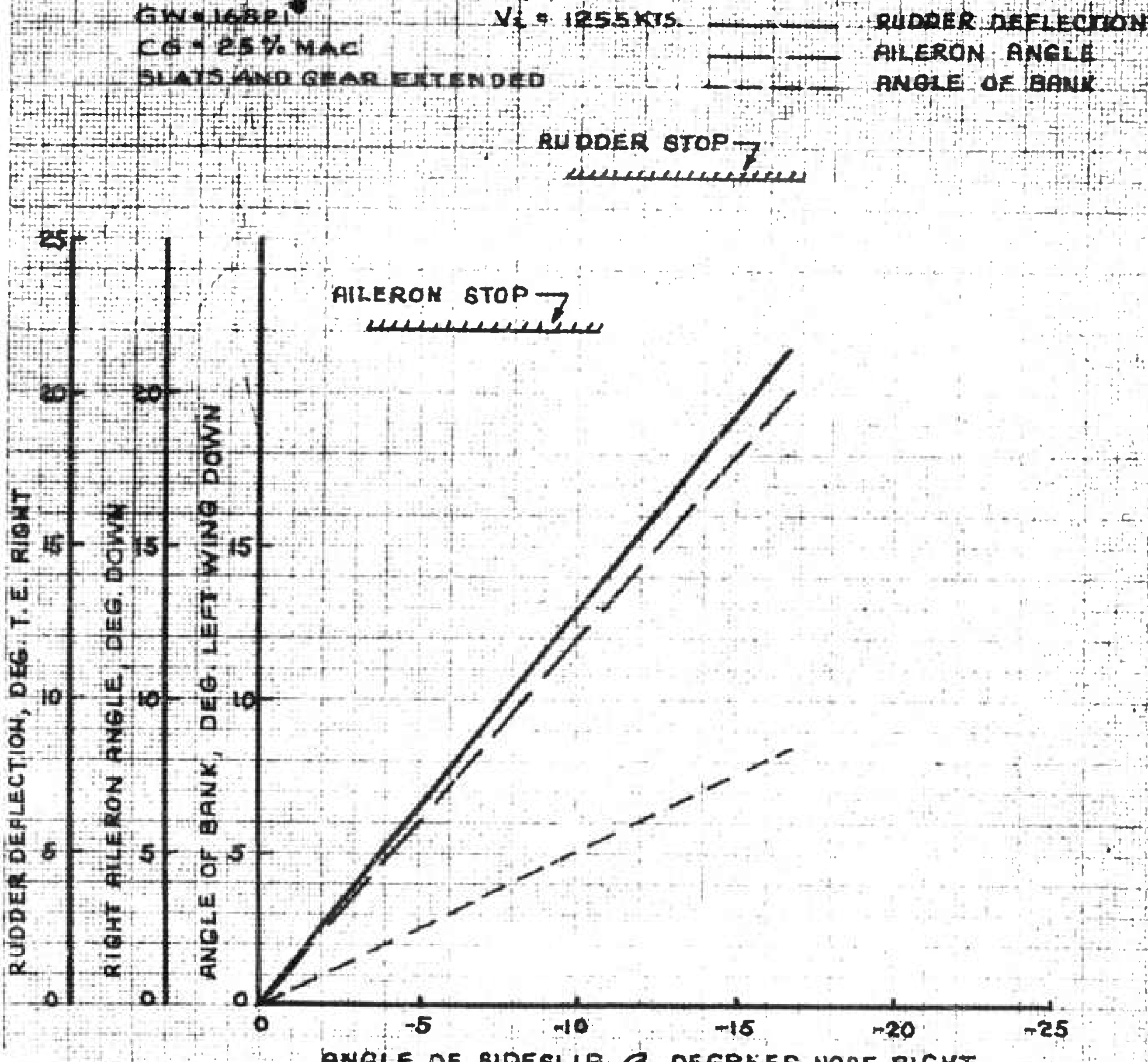
FIG. 56

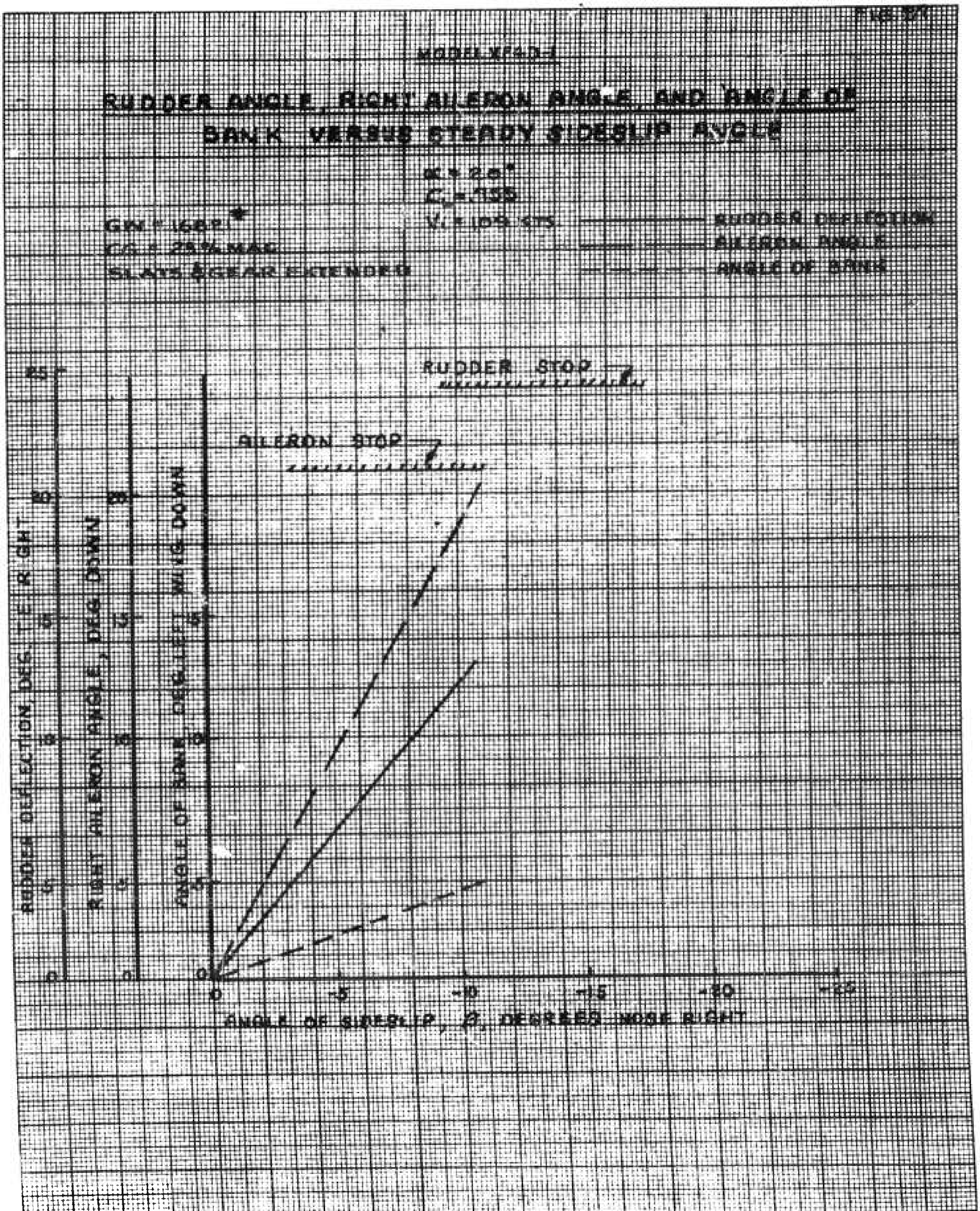
MODEL XF4D-1

RUDDER ANGLE, RIGHT AILERON ANGLE, AND ANGLE OF BANK VERSUS STEADY SIDESLIP ANGLE

$\alpha = 15°$
$C_L = .570$
$V_i = 125.5$ KTS.

GW = 16821#
CG = 25% MAC
SLATS AND GEAR EXTENDED




MODEL XF4D-1
RUDDER ANGLE, RIGHT AILERON ANGLE, AND ANGLE OF BANK VERSUS STEADY SIDESLIP ANGLE
G.W. = 16881#
C.G. = 25% MAC
SLATS & GEAR EXTENDED
RUDDER DEFLECTION
AILERON ANGLE
ANGLE OF BANK
RUDDER STOP
AILERON STOP
RUDDER DEFLECTION, DEG. T.E. RIGHT
RIGHT AILERON ANGLE, DEG DOWN
ANGLE OF BANK, DEG LEFT WING DOWN
ANGLE OF SIDESLIP, β, DEGREES NOSE RIGHT
0
-5
-10
-15
-20
-25
5
10
15
20
25

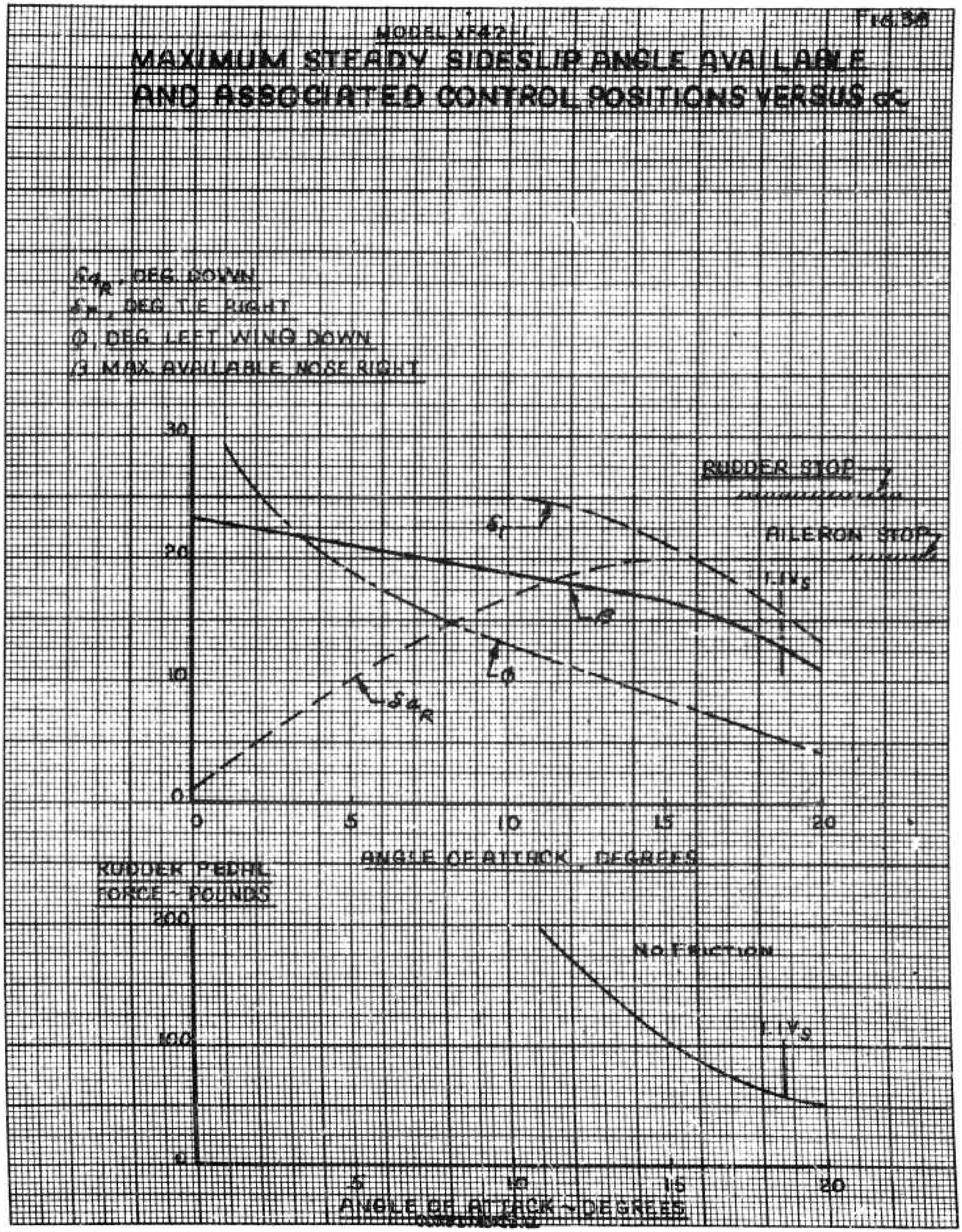


FIG. 38
MODEL XF4D-1
MAXIMUM STEADY SIDESLIP ANGLE AVAILABLE AND ASSOCIATED CONTROL POSITIONS VERSUS α
δ_{a_R}, DEG. DOWN
δ_r, DEG. T.E. RIGHT
ϕ, DEG. LEFT WING DOWN
β MAX. AVAILABLE NOSE RIGHT
RUDDER STOP
AILERON STOP
1.1 V_S
δ_r
β
ϕ
δ_{a_R}
30
20
10
0
0
5
10
15
20
ANGLE OF ATTACK, DEGREES
RUDDER PEDAL FORCE - POUNDS
200
100
0
NO FRICTION
1.1 V_S
5
10
15
20
ANGLE OF ATTACK ~ DEGREES

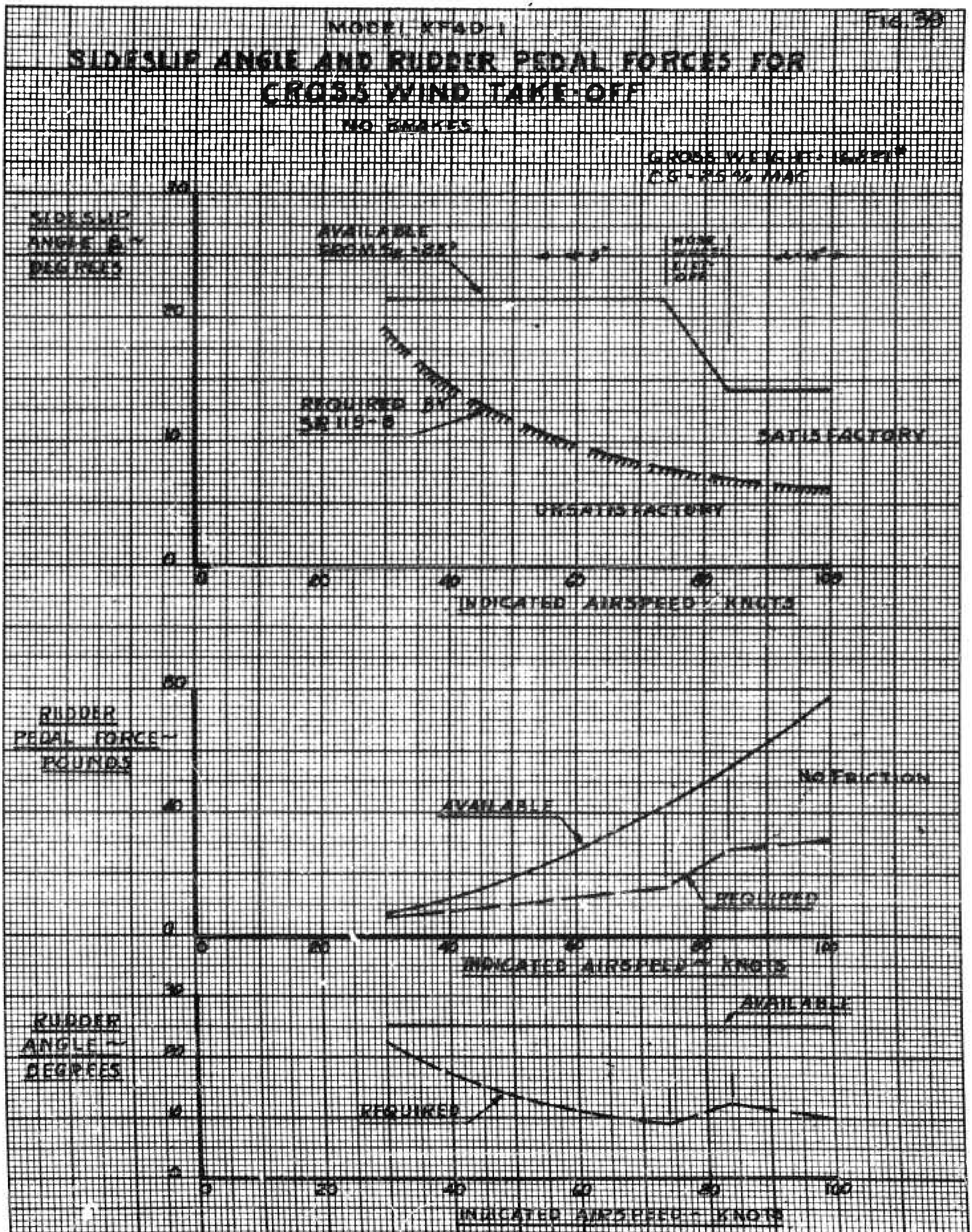


FIG. 30
MODEL XF4D-1
SIDESLIP ANGLE AND RUDDER PEDAL FORCES FOR
CROSS WIND TAKE-OFF
NO BRAKES
SIDESLIP ANGLE β ~ DEGREES
AVAILABLE FROM δr = 25°
NOSE WHEEL LIFT OFF
REQUIRED BY SR 119-B
SATISFACTORY
UNSATISFACTORY
INDICATED AIRSPEED ~ KNOTS
RUDDER PEDAL FORCE ~ POUNDS
NO FRICTION
AVAILABLE
REQUIRED
INDICATED AIRSPEED ~ KNOTS
RUDDER ANGLE ~ DEGREES
AVAILABLE
REQUIRED
INDICATED AIRSPEED ~ KNOTS

Since analysis and design of the rate-gyro and rudder pedal force link system is not complete, final rudder pedal forces for the case where the system is in operation are not yet determined. However, design of the force link is proceeding with the rudder pedal force requirements of Reference 4 in mind. Final rudder pedal forces required for steady turns and sideslips will be presented in the forthcoming Reference 7 .

8.3 Lateral Characteristics

8.3.1 Dihedral Effect

The static lateral stability parameter, C_{ℓ_β}, is plotted as a function of lift coefficient in Figure 26 . C_{ℓ_β} is positive over the entire flight range of the airplane , increasing from a value of -.00038 at zero lift to -.00275 at C_L = .850 and satisfies stick fixed dihedral effect requirements.

Reference 4 states that positive static stick free dihedral effect shall exist and shall be evidenced during sideslips by aileron deflection and control force towards the leading wing being required to depress the leading wing. By referring to Figure 38 it may be seen this condition is satisfied.

Examination of Figures 27,28,29 and 30 indicates no evidence of reversal in rolling velocity due to dihedral effect.

8.3.2 Lateral Control

8.3.2.1 Normal Control Configuration

The effect of trimmer on rolling characteristics is small. Referring to Figures 40 and 41 , it is seen that trimmer position will have some effect on $\frac{Pb}{2V}$ and rolling velocity at high angles of attack, but none at medium and low angles of attack. This is due to the slight loss in rolling effectiveness at large lateral elevon angles that are obtained when considerable elevon deflection is required for longitudinal trim, (low speeds).

It is seen from Figures 40 and 41 that rolling characteristics are excellent; being considerably in excess of the requirements of Reference 4 at all speeds except near the stalling velocity. At 1.1 V_{stall}, the maximum $\frac{Pb}{2V}$ obtained is .07 whereas .09 is required to meet SR119-B.

This apparent deficiency is not considered serious. Comparison of the zero sideslip rolling characteristics of the XF4D-1 with those of the XF3D-1, an airplane considered to have excellent low speed lateral control, shows the XF4D-1 to be capable of a $\frac{Pb}{2V}$ of .175 with full control deflection as compared to .125 for the XF3D-1 under the same

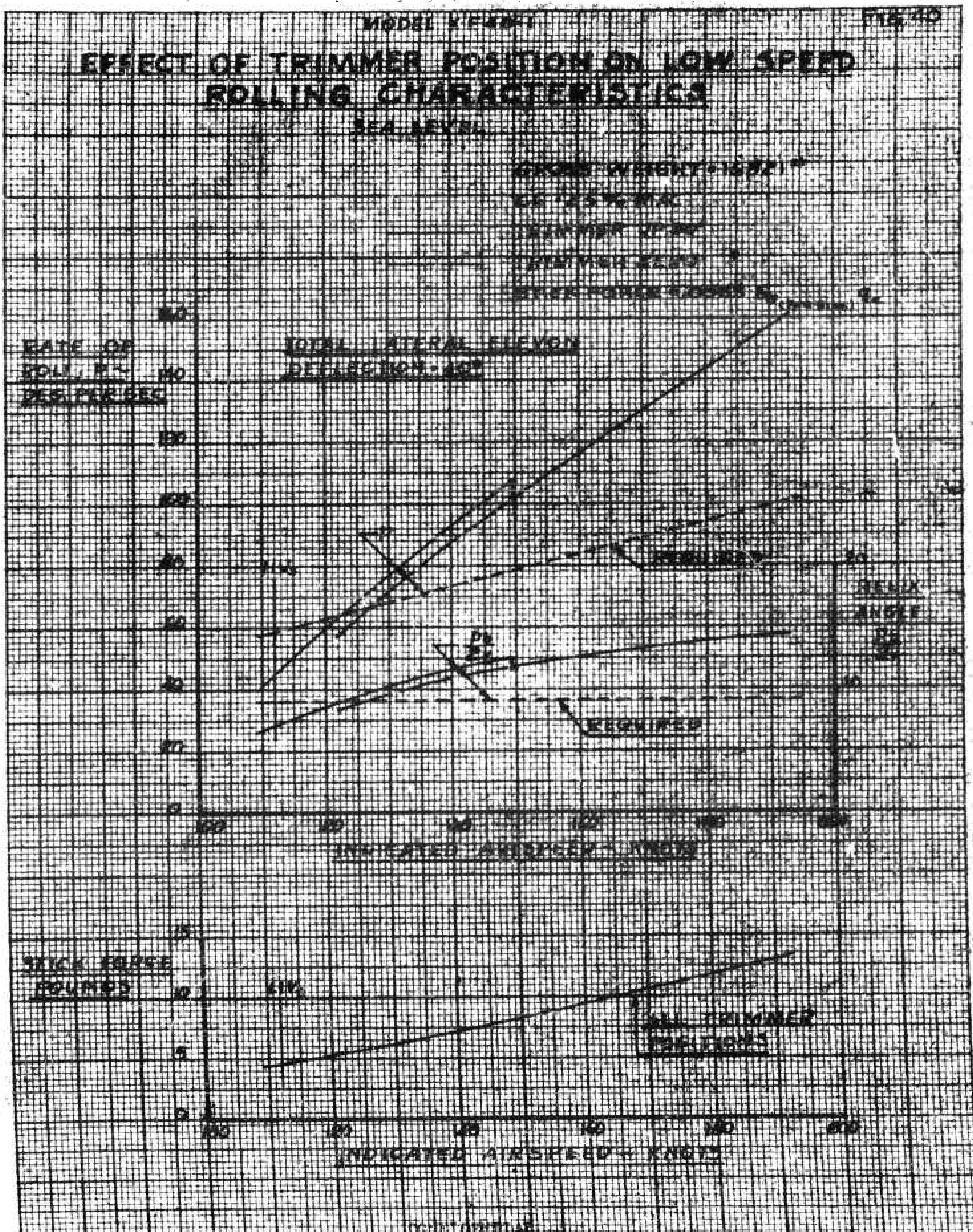


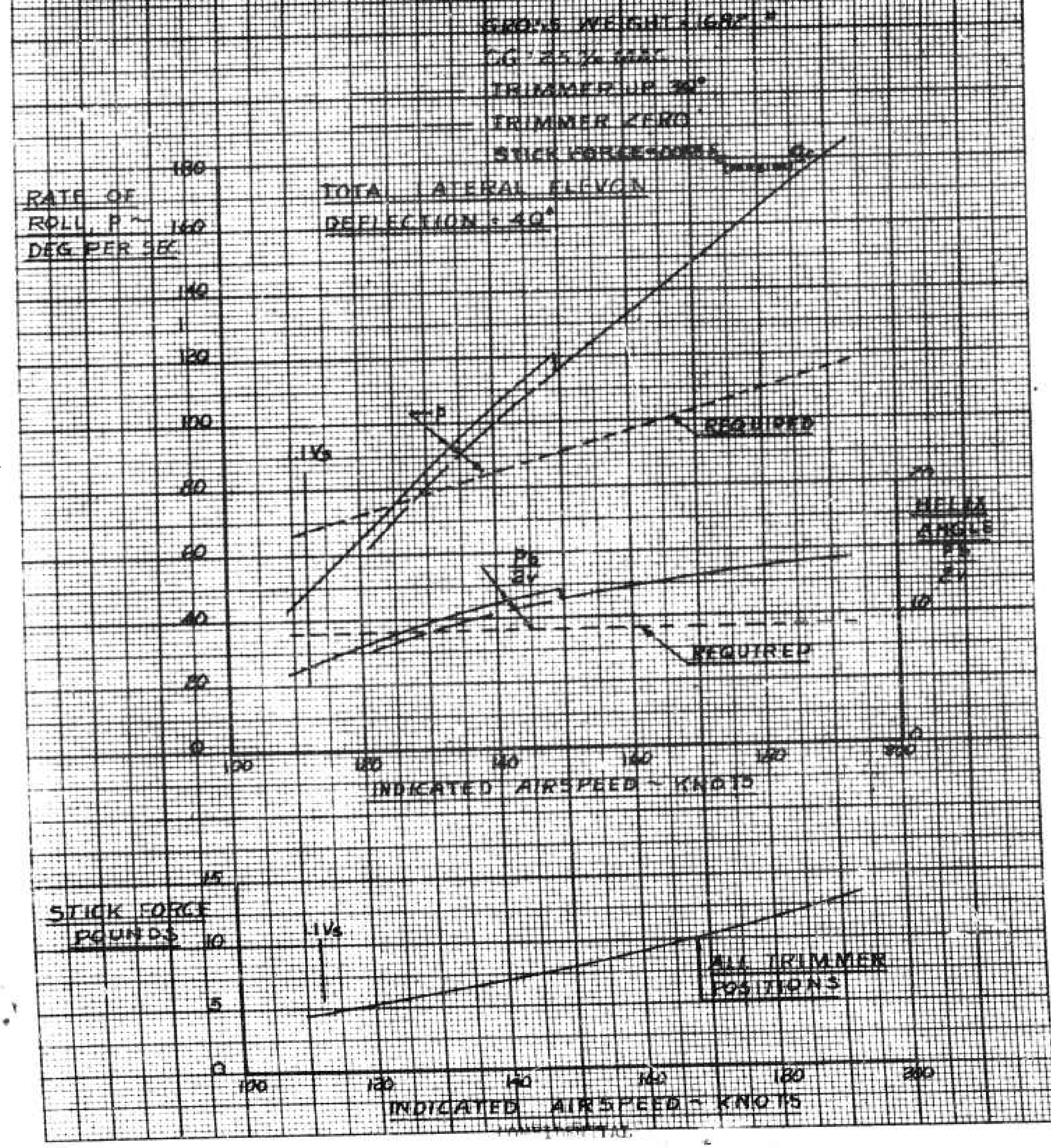
FIG. 40
MODEL XF4D-1
EFFECT OF TRIMMER POSITION ON LOW SPEED ROLLING CHARACTERISTICS
SEA LEVEL
RATE OF ROLL, P ~ DEG PER SEC
TOTAL LATERAL ELEVON DEFLECTION
REQUIRED
BANK ANGLE
REQUIRED
INDICATED AIRSPEED ~ KNOTS
STICK FORCE POUNDS
ALL TRIMMER POSITIONS
INDICATED AIRSPEED ~ KNOTS

FIG. 41

MODEL XF4D-1

EFFECT OF TRIMMER POSITION ON LOW SPEED ROLLING CHARACTERISTICS

10000 FT



condition. The apparent loss in $\frac{Pb}{2V}$ of .105 in the case of the XF4D-1 is due to K_β, the roll reduction factor due to sideslip. In order for the full effect of K_β to be experienced, it is estimated that at least 20° of sideslip must be obtained at 1.1 V_s. It is further believed that low speed rolls executed at near stalling speeds will more closely approximate a zero sideslip condition than a rudder fixed condition. Under this assumption, the XF4D-1 should have as good or better lateral characteristic at low speeds than those obtained on the pilot accepted XF3D-1. It should also be noted that whereas the XF3D-1 has a maximum rolling velocity of 35°/sec. in the landing condition, the XF4D-1 has almost 50°/sec by virtue of its shorter span.

Lateral stick forces obtained during fully deflected elevon rolls are plotted on Figures 40 and 41 . As in the case of longitudinal stick forces, lateral forces are supplied with a synthetic force feel system whose output is proportional to elevon deflection and dynamic pressure. Stick forces are moderate and easily meet the requirements of Reference 4 .

Estimated loss of lateral control due to wing twist and sideslip is presented in Figures 42 and 43 in terms of their respective reduction, factors, K_τ and K_β .

8.3.2.2 Emergency Control Configuration

During emergency control operation, lateral control and hinge moment are obtained from the outboard elevons only. Reference 4 requires that a minimum of 15°/sec rate of roll be obtained with no more than 30 pounds stick force. Figure 44 shows stick force required to produce a rate of roll of 15°/sec, and the rate of roll obtained from 30 pounds stick force is plotted on Figure 45 . Examination of these curves reveals that the requirements of Reference 4 are not satisfied.

Using the same argument presented in Section 8.3.2.1, the low speed rolling velocity obtained from 30 pounds stick force can be increased from approximately 10°/sec. to 25°/sec. by using rudder to make zero sideslip rolls. It is felt the latter figure will more nearly approximate the maximum low speed rolling velocity available under actual flight conditions. Moreover, two independent hydraulic systems must fail before it becomes necessary to use the manual emergency system.

Fig. 42

MODEL XF4D-1

ROLL REDUCTION FACTOR DUE TO WING TWIST VERSUS MACH NUMBER

(BASED ON STRESS DATA AND VARIED WITH q)

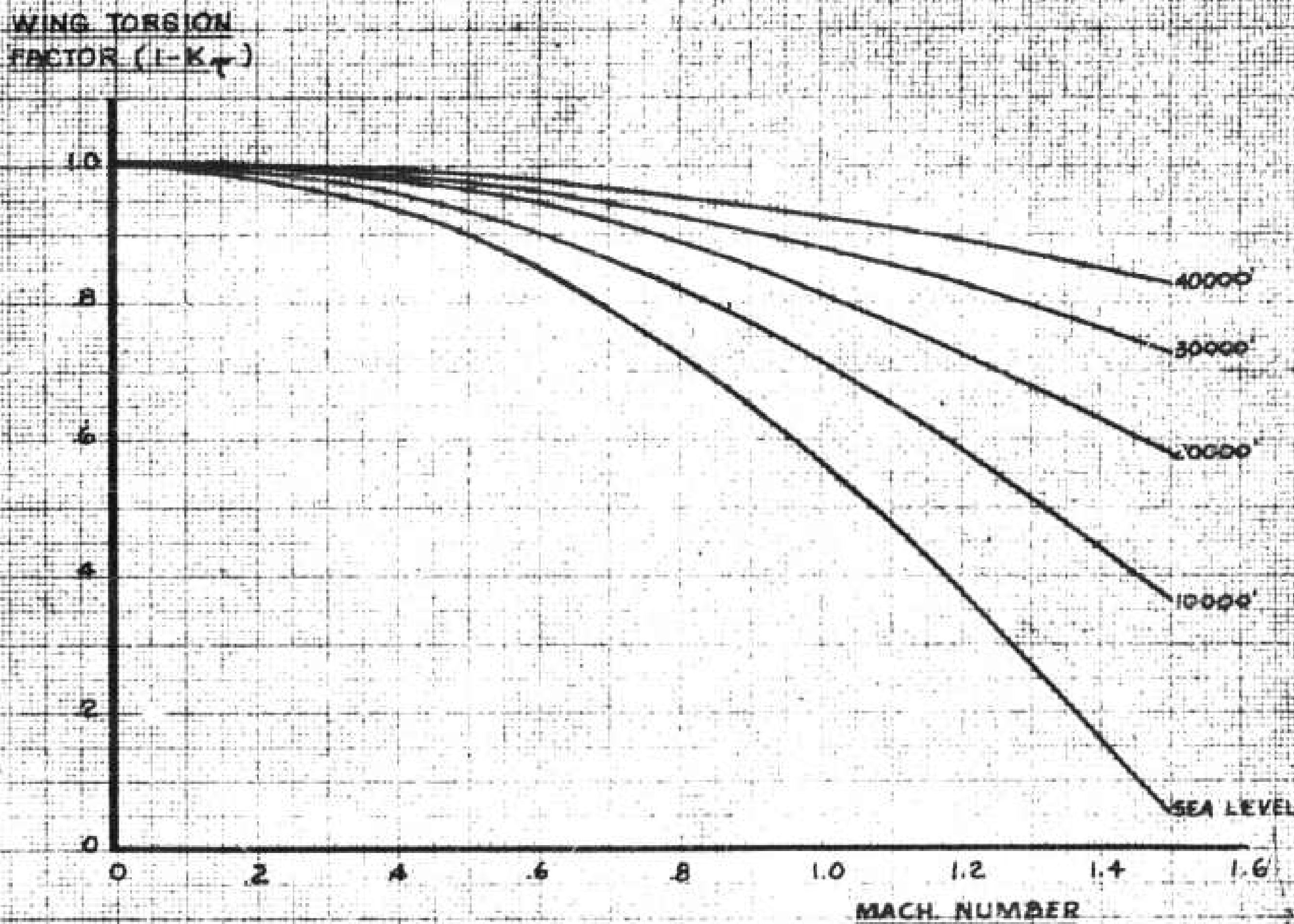


FIG 43

MODEL XF4D-1

ROLL REDUCTION FACTOR DUE TO SIDESLIP AND RATE OF YAW VERSUS C_L

RUDDER FIXED

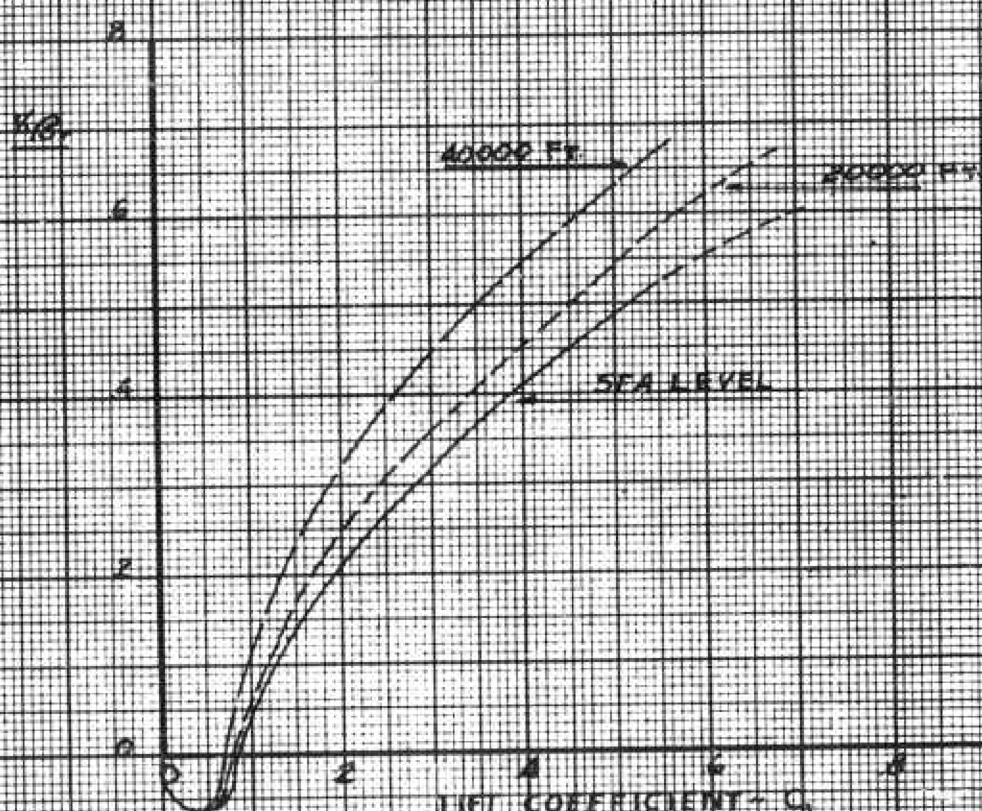


FIG. 44

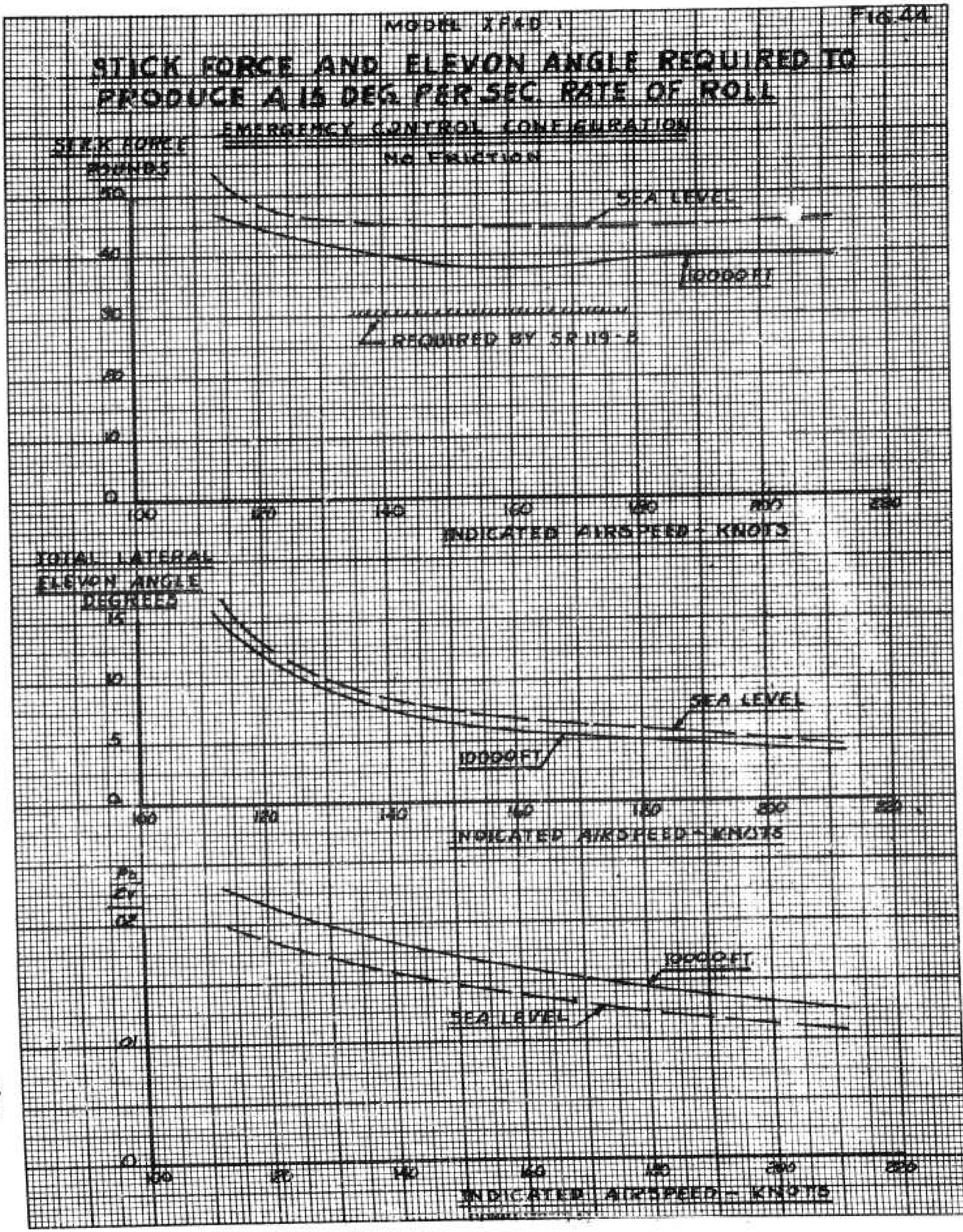
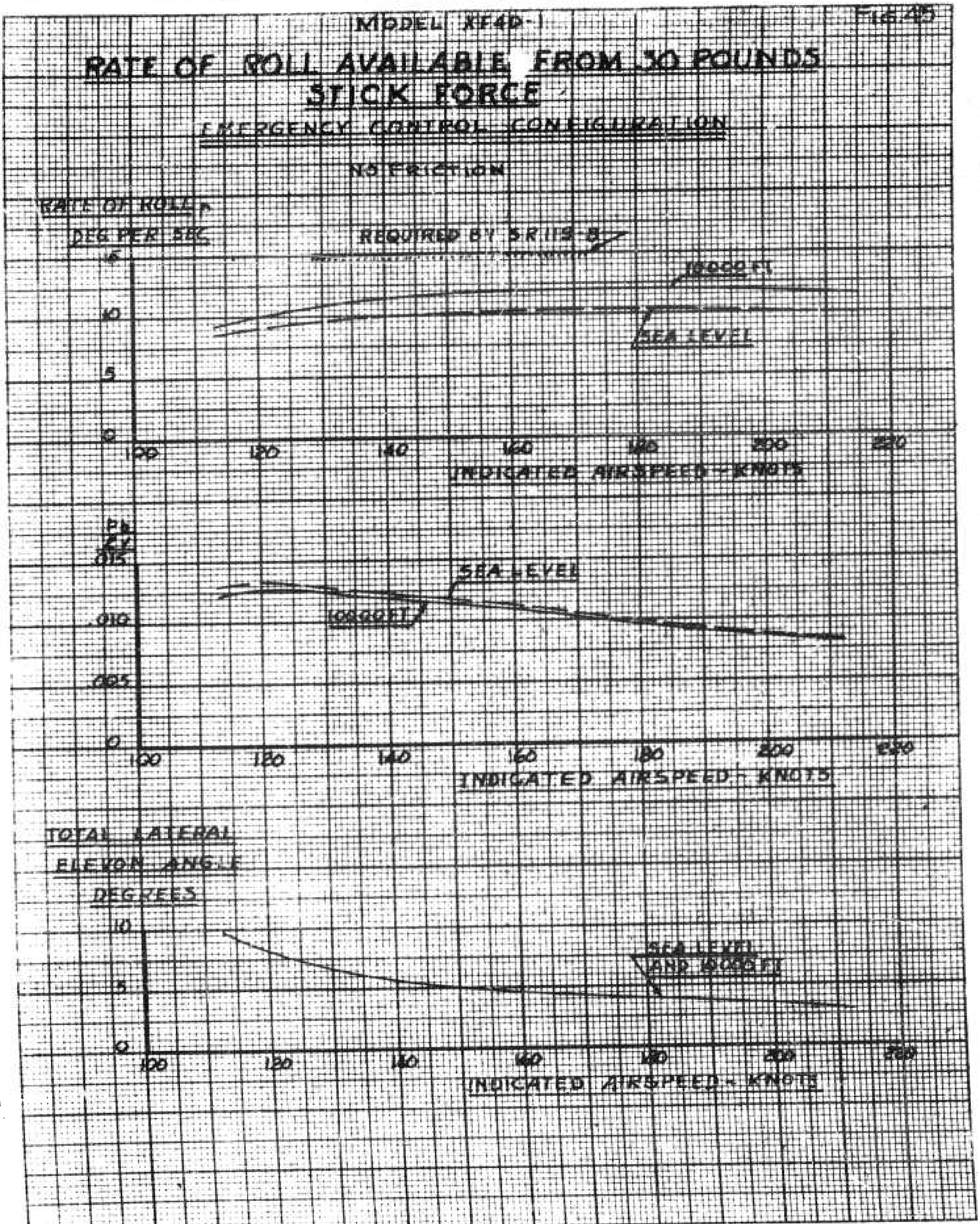

MODEL XF4D-1
STICK FORCE AND ELEVON ANGLE REQUIRED TO PRODUCE A 15 DEG. PER SEC. RATE OF ROLL
EMERGENCY CONTROL CONFIGURATION
NO FRICTION
STICK FORCE POUNDS
SEA LEVEL
10000 FT
REQUIRED BY SR 119-B
INDICATED AIRSPEED - KNOTS
TOTAL LATERAL ELEVON ANGLE DEGREES
SEA LEVEL
10000 FT
INDICATED AIRSPEED - KNOTS
10000 FT
SEA LEVEL
INDICATED AIRSPEED - KNOTS

FIG. 45


MODEL XF4D-1
RATE OF ROLL AVAILABLE FROM 30 POUNDS STICK FORCE
EMERGENCY CONTROL CONFIGURATION
NO FRICTION
RATE OF ROLL, P DEG PER SEC
REQUIRED BY SR119-B
10000 FT
SEA LEVEL
15
10
5
0
100
120
140
160
180
200
220
INDICATED AIRSPEED - KNOTS
Pb/2V
.015
.010
.005
0
SEA LEVEL
10000 FT
TOTAL LATERAL ELEVON ANGLE DEGREES
SEA LEVEL AND 10000 FT

9.0 CONCLUSIONS AND RECOMMENDATIONS

On the basis of the analysis of Part I of this report, it is concluded that the low speed flying qualities of the XF4D-1 will be generally satisfactory, although in several respects they appear to be marginal. To insure fully satisfactory characteristics of the prototype, the following recommendations are made.

1. The center of gravity should not exceed 22% MAC maximum forward with the gear extended, and 25% MAC maximum aft with the gear retracted.

2. Marginal dynamic longitudinal damping characteristics should be recognized, and provisions made for introducing artificial damping into the longitudinal control system if poor damping is verified during flight tests.

10.0 REFERENCES

1. Guggenheim Aeronautical Laboratory, California Institute of Technology, Pasadena California: "Report on Wind Tunnel Tests of a 17.91% Scale Model of the Douglas (El Segundo) XF4D-1 Airplane." GALCIT Report No. 555, (not yet published).

2. Southern California Cooperative Wind Tunnel, Pasadena California: "Report on Wind Tunnel Tests at Transonic Speeds of a $\frac{1}{40.2}$ Scale Left-Hand Reflection Model of the Douglas 571. CWT Report No. 115, (not yet published).

3. Huff, W.W. and Bratt, R.W.: "Low Speed Stability and Control Characteristics of the Douglas Model XF4D-1 Airplane." Douglas Report ES 21391, February 18, 1949.

4. Navy Bureau of Aeronautics Specification: "Specifications for Flying Qualities of Piloted Airplanes." SR 119-B, June 1, 1948.

5. McWherter, R.C., Huff, W.W., Fossier, M.W.: "Low Speed Stability and Control Characteristics of the Douglas Model 571 as Determined from Wind Tunnel Tests." Douglas Report ES 21253, August 31, 1948.

6. Huff, W.W.: "Stability and Control Characteristics of Douglas Model 591 and 591-A Airplanes." Douglas Report ES 21260, September 16, 1948.

7. Bratt, R.W.: "Investigation of the Effect of the Yaw Damper on the Lateral-Directional Oscillation of the XF4D-1 Airplane." Douglas Report ES 15301, (not yet published).